

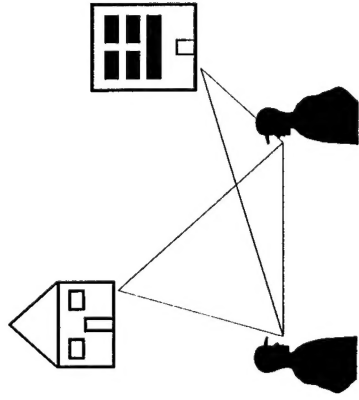
REPORT DOCUMENTATION PAGE

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Wireless Propagation Measurements, Analysis, and Modeling



SSC-SD D855

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Outline

- Measurement Goals and Capabilities
- Multipath Tutorial
- Sample Results
 - Urban Channel
 - HMMWV Motion
 - Human Mount w/Motion
 - Various Antenna Heights
 - Many Channels
 - Path Loss vs. Delay Spread
- Model Comparisons

SSC-SD Measurement Goals

- **Measure Channel Responses**
 - Urban/Suburban, Hills/Trees, Airfield
 - Antennas close to buildings
 - Antennas mounted on humans in motion
 - Low antenna heights
 - VHF, UHF, ISM, LBand
- **Compare w/existing Propagation Models**

Measurement System Capabilities

- Long Duration (25s)
- High Resolution (12m)
- Long Range (10km)
- Frequency Versatile (30MHz-2GHz)
- Severe Environments (Heavy Urban)
- Arbitrary Waveform Capability

Data Applications

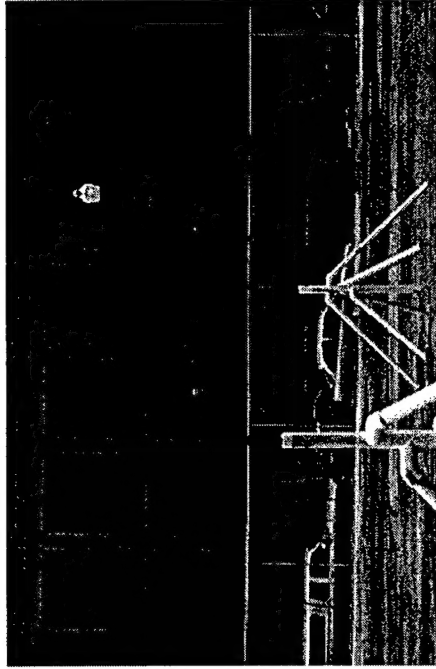
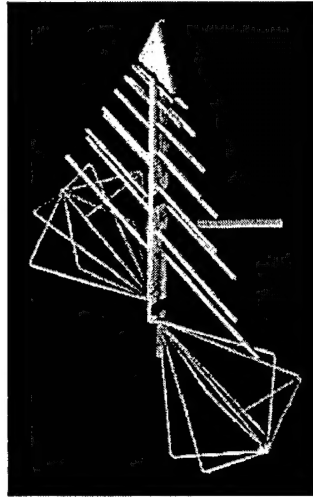
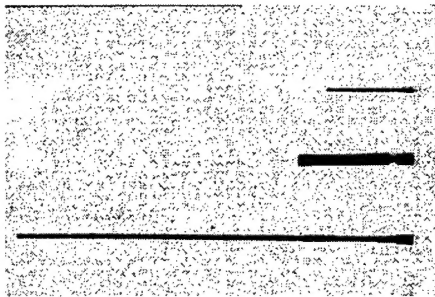


- **Propagation Science**
- **Radio Design**
 - **Algorithm development/testing**
 - **Waveform development/testing**
 - **Antenna development/testing**
 - **Transmit power selection/power control design**
 - **Frequency and BW selection**
 - **Computation update requirements**
- **Network Modeling**
- **Network Design**

Transmitter/Receiver

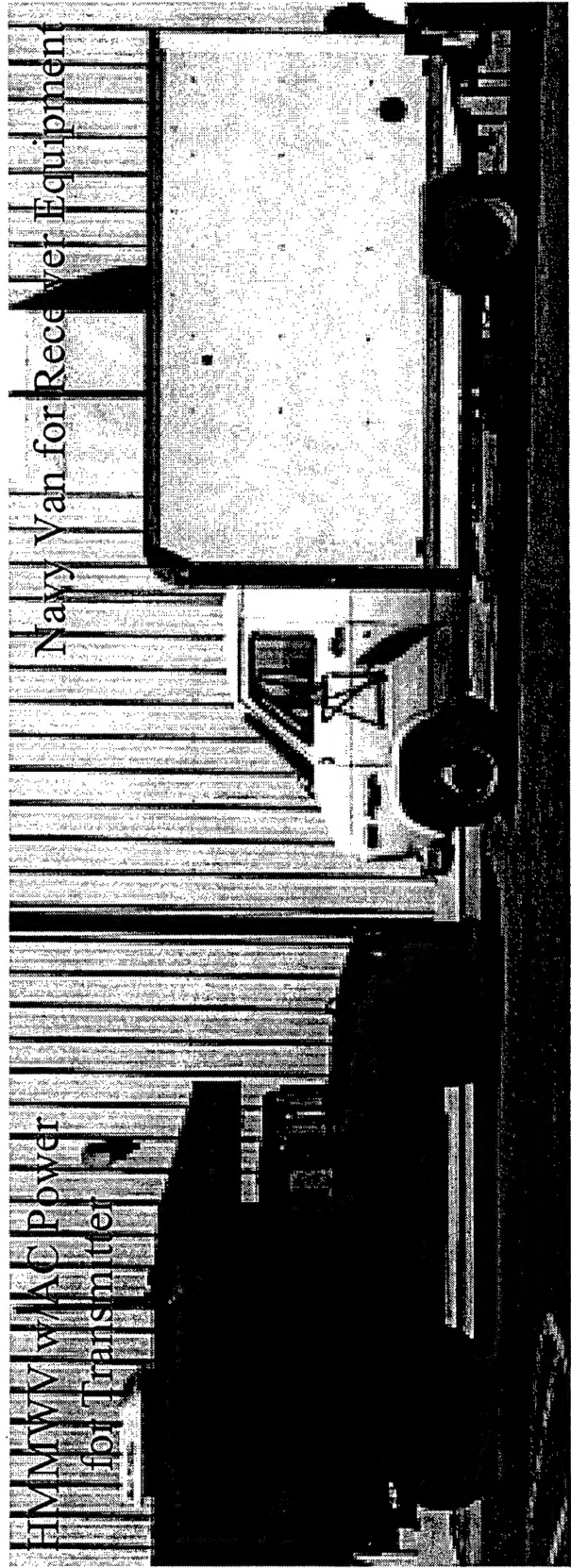
Transmitter Antennas

Receiver Antennas



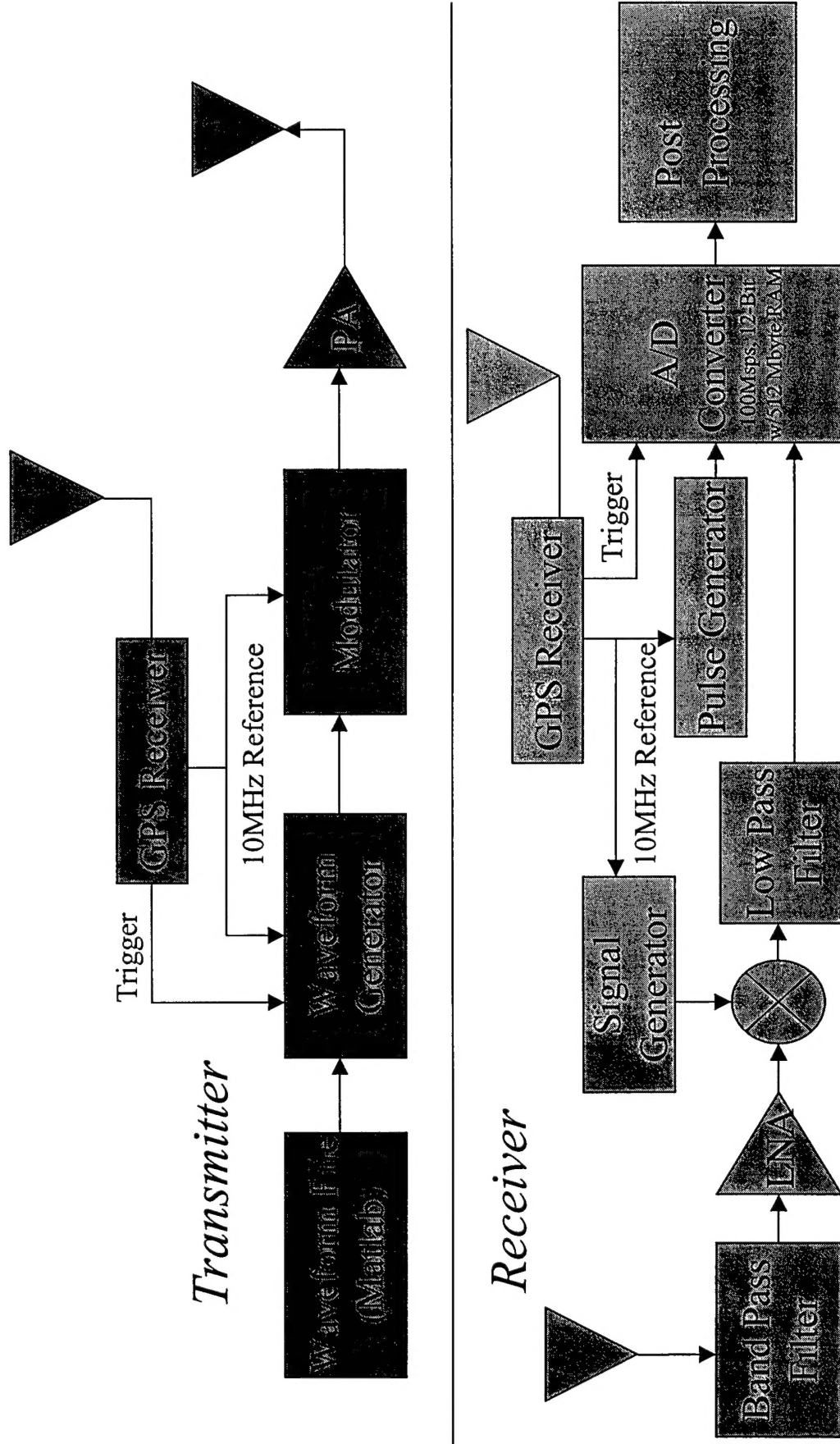
HMMWV w/AC Power
for Transmitter

Navy Van for Receiver Equipment



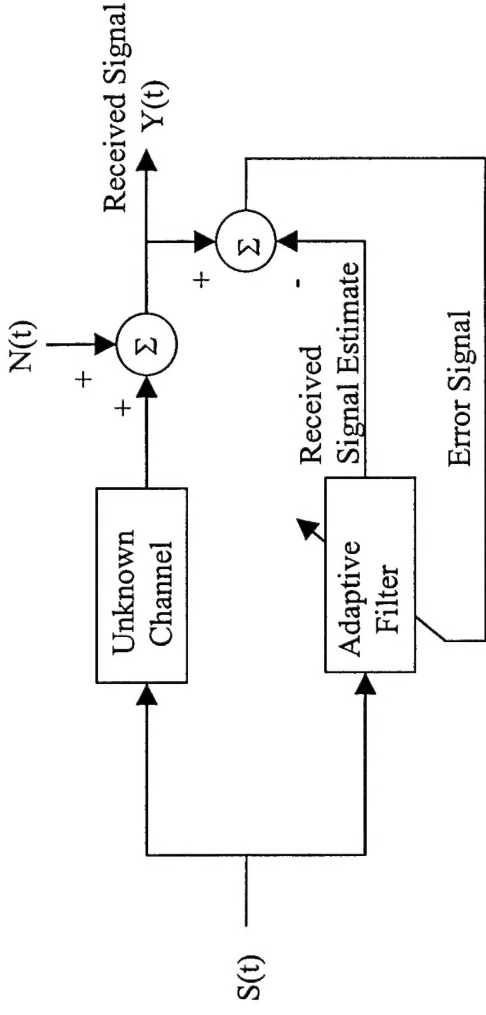
Propagation Testbed

30MHz-2GHz



Adaptive Channel Estimation

- Channel Modeling Algorithm:

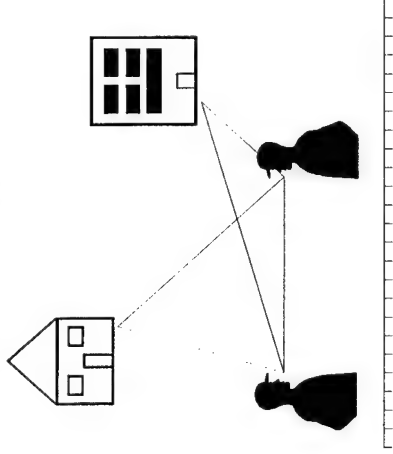


- Adaptive FIR Channel Estimation Filter:
 - 3 Phases:
 - Acquisition - Recursive Least Squares (RLS)
 - Training - Normalized Gradient Decent (NLMS)
 - Tracking - Normalized Gradient Decent (NLMS)
 - Filter Tap Length - 240 Taps

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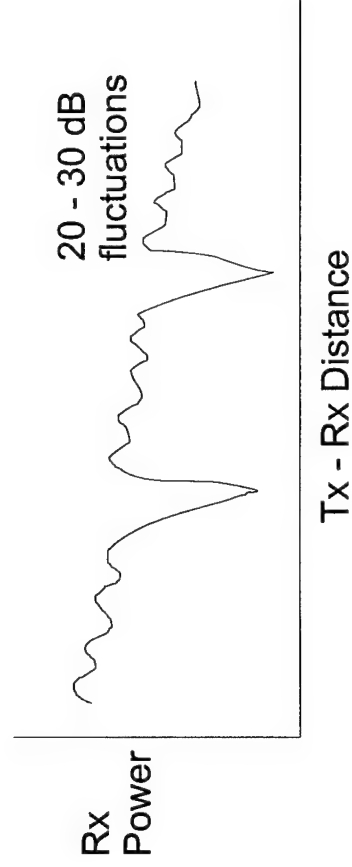
Multipath



- Exact solution: Maxwell's equations and Boundary Conditions
- Approximate solution: Trace rays using geometric optic rules
- Better: Add edge diffraction and transmission through wall
- But: Need a good geometrical description of the environment
- Alternative: STATISTICAL DESCRIPTION

Narrowband Signals

$$p_{\tau} = p_o \left| \sum_{i=1}^L \frac{a_i}{d_i} e^{j\phi_i} \right|^2$$



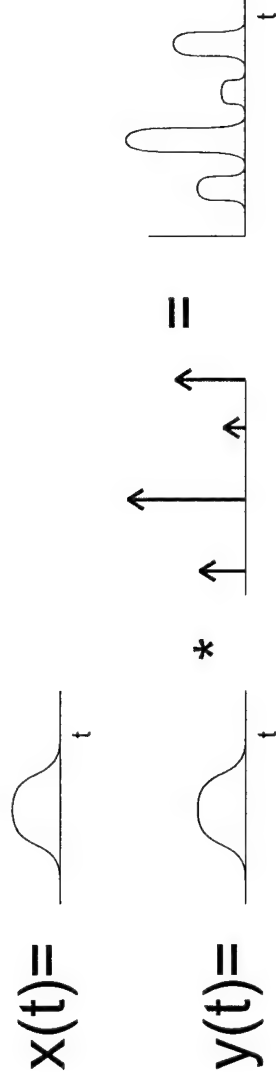
Wideband Signal

$$\begin{aligned}
 h(\tau, t) &= \sum_{i=1}^L \beta_i e^{j\varphi_i(t-\tau_i)} \\
 y(t) &= \int x(t-\tau') h(\tau, \tau') \\
 &= \int x(t-\tau') \sum_{i=1}^L \beta_i e^{j\varphi_i} \delta(\tau' - \tau_i) d\tau' \\
 &= \sum_{i=1}^L \beta_i e^{j\varphi_i} x(t - \tau_i)
 \end{aligned}$$

Ideal Case (Infinite BW)

$$\begin{aligned}
 \text{Let } x(t) &= \delta(t) \\
 \Rightarrow y(t) &= h(\tau, t) \\
 |y(t)|^2 &= y(t)y^*(t) \\
 &= \sum_{i=1}^L \sum_{k=1}^L \beta_i \beta_k^* e^{j(\varphi_i - \varphi_k)} \delta(t - \tau_i) \delta(t - \tau_k) \\
 p &= \int |y(t)|^2 dt = \\
 &= \sum_{i=1}^L \sum_{k=1}^L \beta_i \beta_k^* e^{j(\varphi_i - \varphi_k)} \int \delta(t - \tau_i) \delta(t - \tau_k) dt \\
 &= \sum_{i=1}^L |\beta_i|^2
 \end{aligned}$$

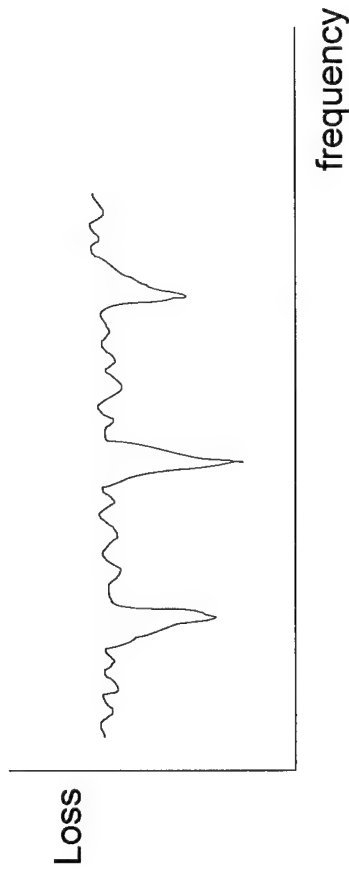
Power Delay Profile (Practical Case)



σ = delay spread

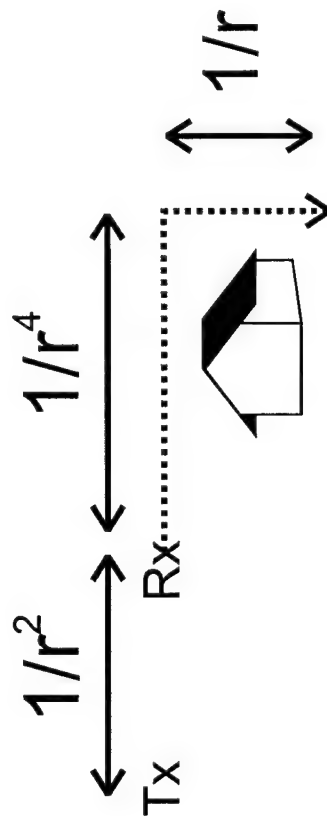
Smearing due to convolution.

Channel Frequency Response



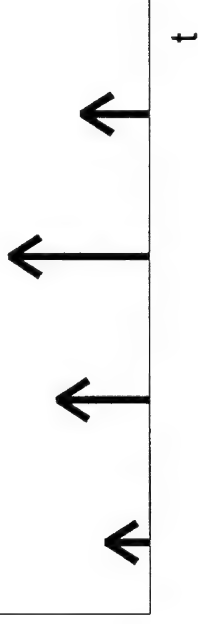
Modeling

- Path Loss (JTC)

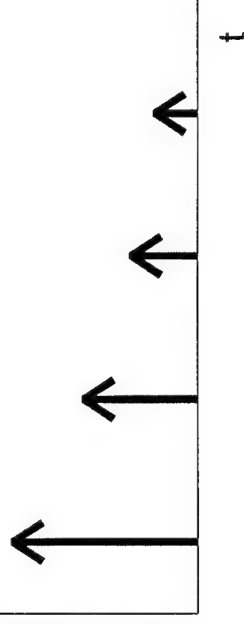


Canonical Tapped Delay Line Model

Urban High Rise

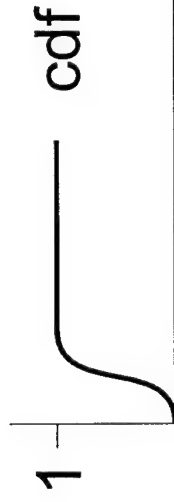


Urban Low Rise



Motion Measurements (8 Sec)

- A collection of channel realization in a single measurement



Loss on Delay Sprea

Motion Measurements (8 Sec)

- Compute means and
 - 1) Compare to each other
 - different carrier freqs
 - different environments
 - 2) Compare to Models
 - JTC
 - Hata
 - TIREM

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Urban San Diego



Airfield and Urban Delay

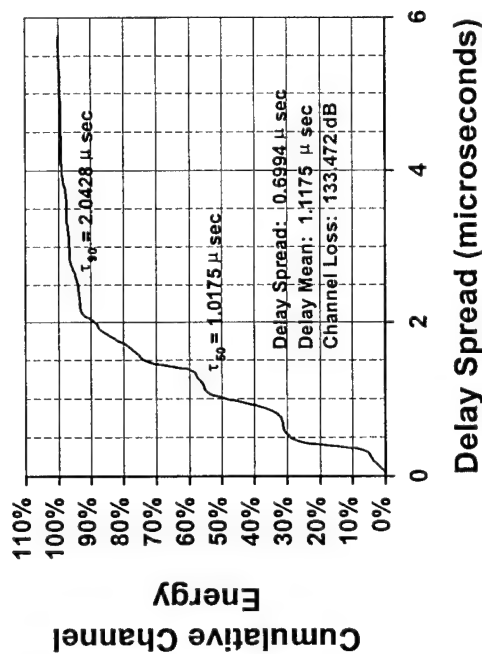
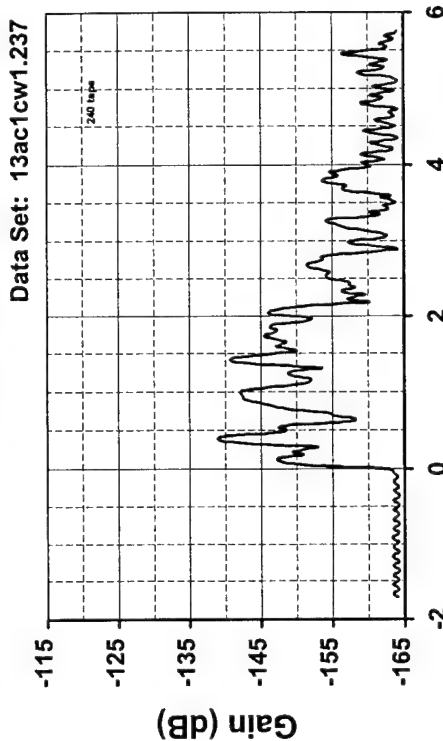
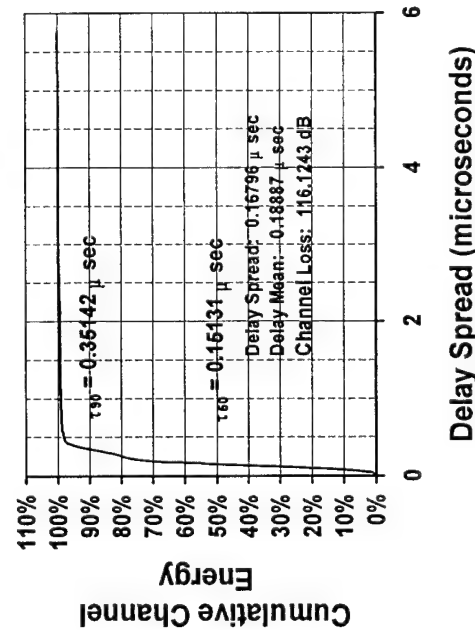
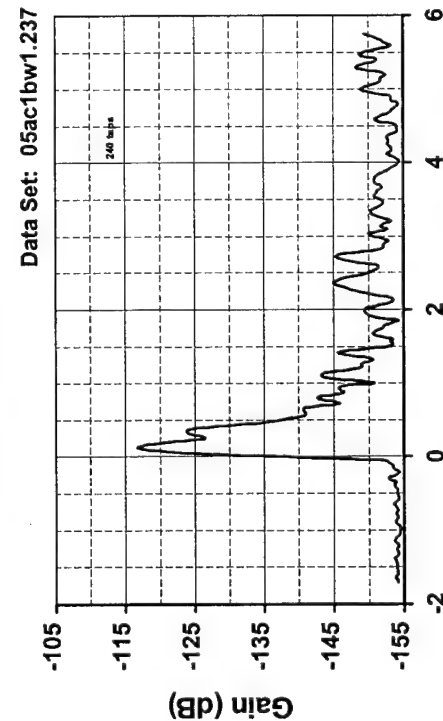
Profiles

Airfield

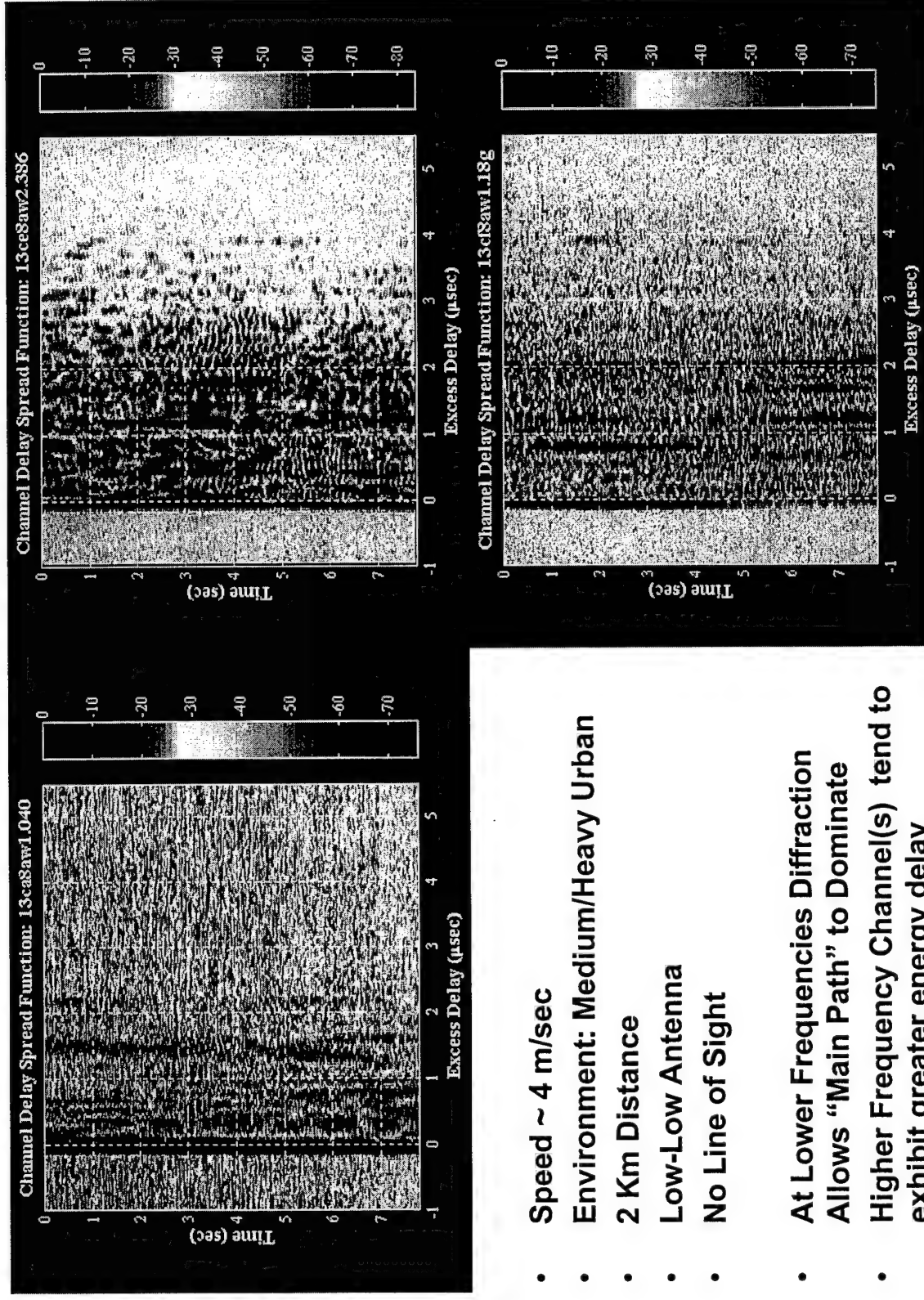
(3.48 km; 237 MHz)

Urban

(2.15 km; 237 MHz)

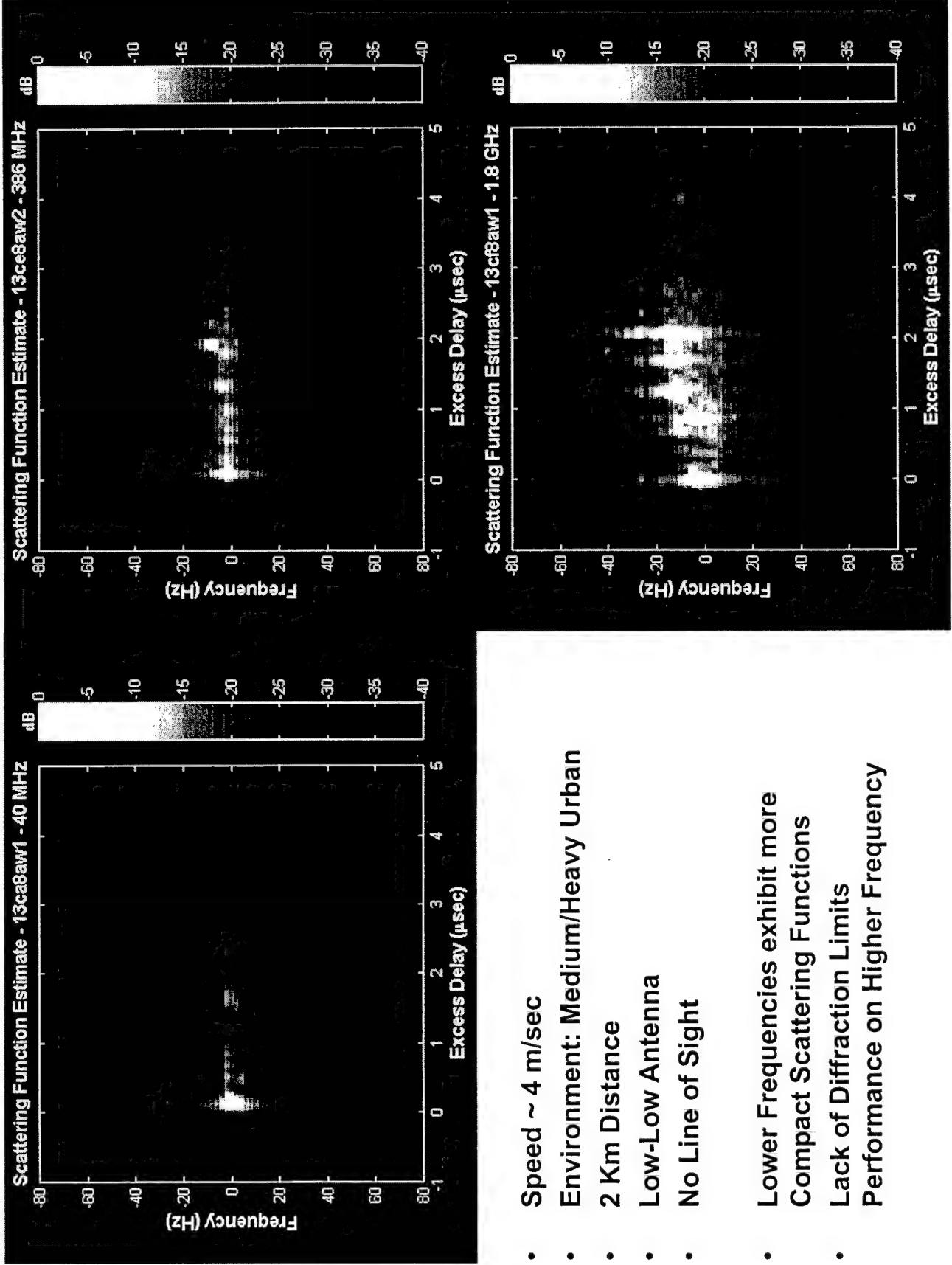


Channel Estimates - Motion



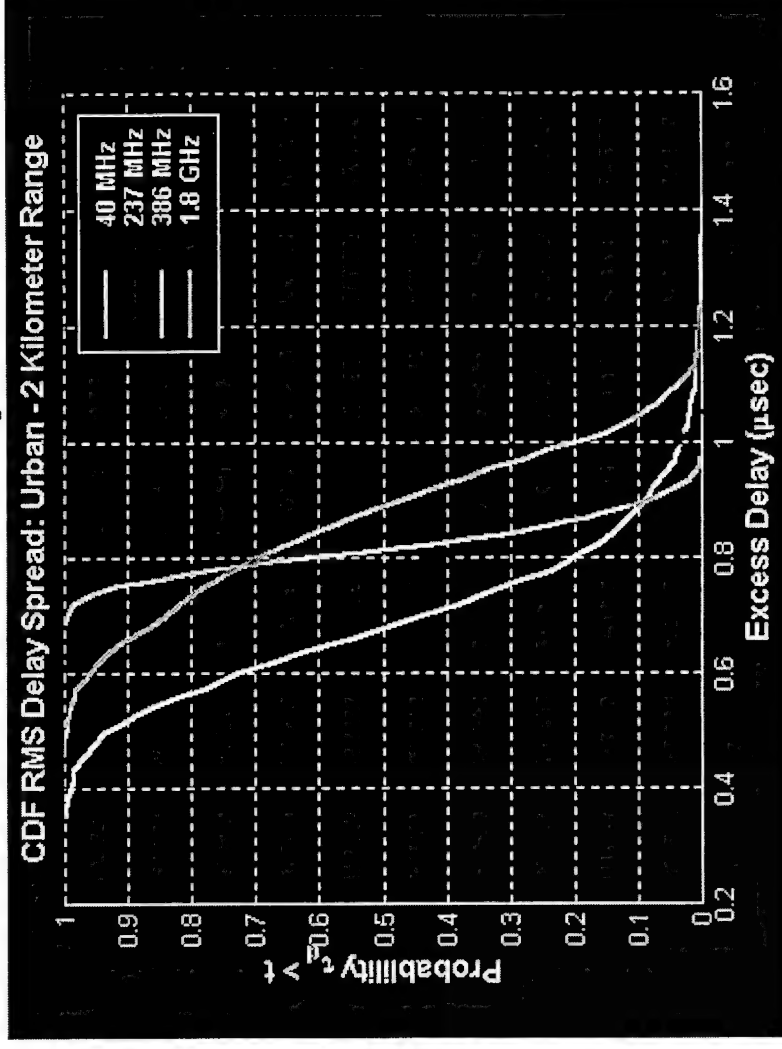
- Speed ~ 4 m/sec
- Environment: Medium/Heavy Urban
- 2 Km Distance
- Low-Low Antenna
- No Line of Sight
- At Lower Frequencies Diffraction Allows "Main Path" to Dominate
- Higher Frequency Channel(s) tend to exhibit greater energy delay

Scattering Functions - Motion



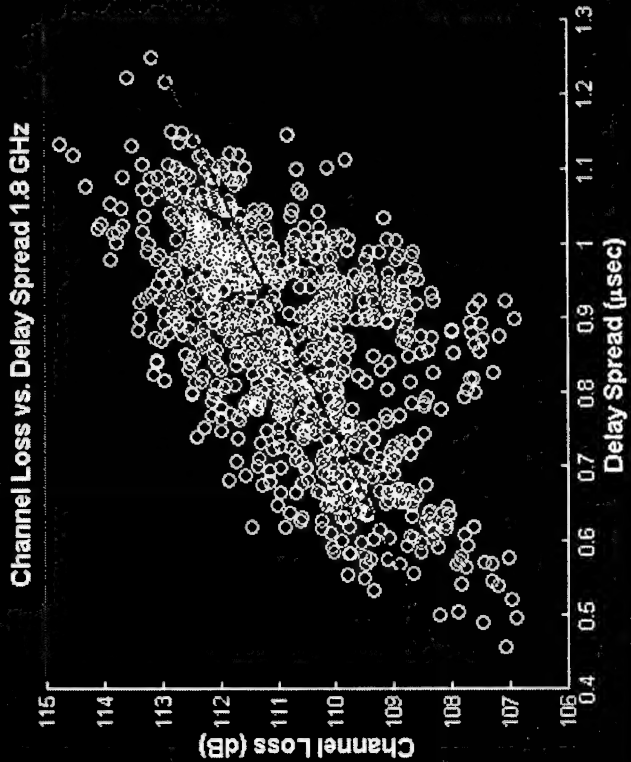
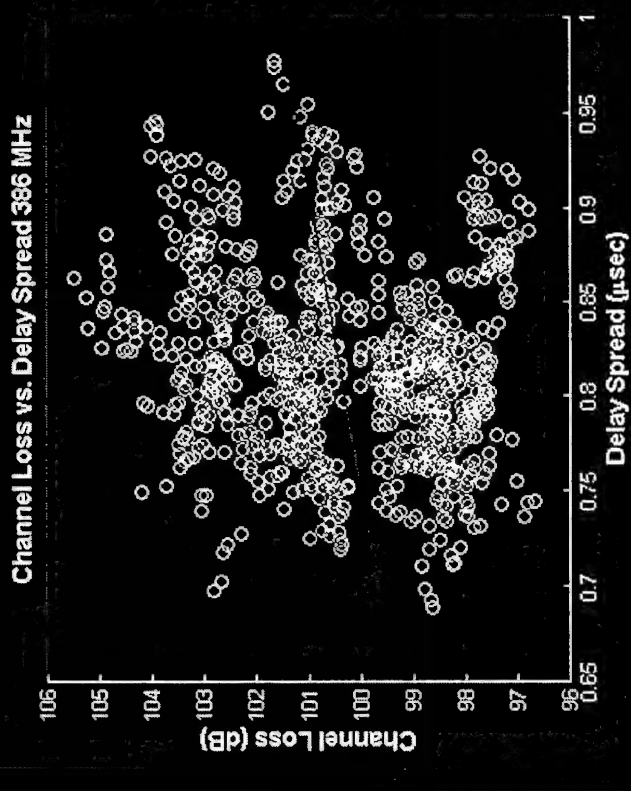
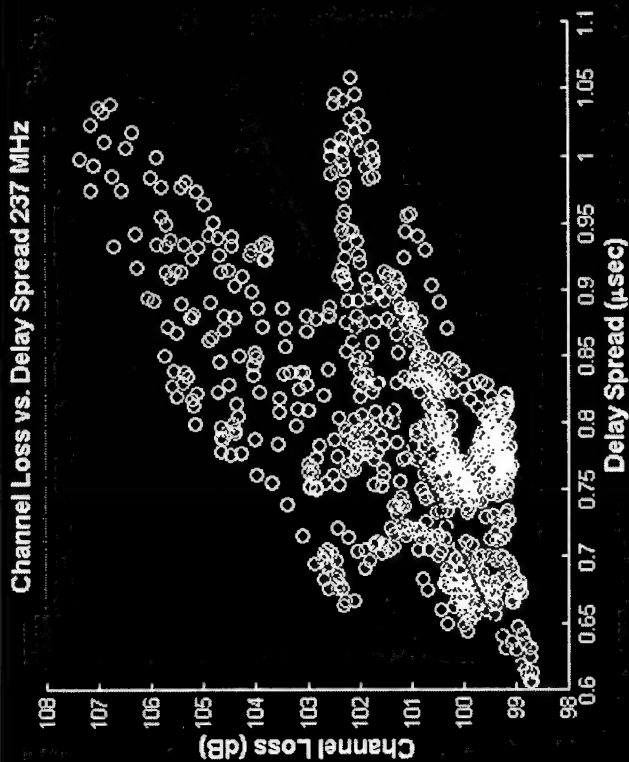
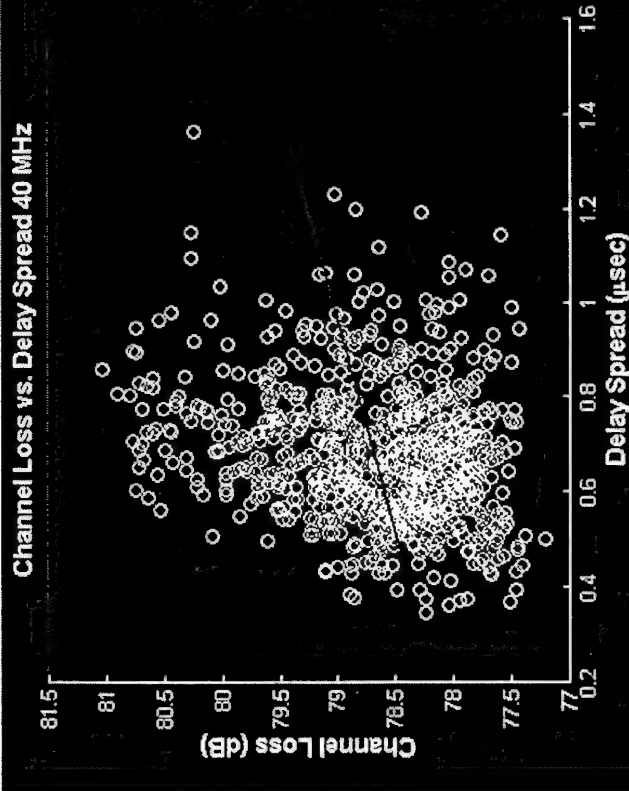
- Speed ~ 4 m/sec
- Environment: Medium/Heavy Urban
- 2 Km Distance
- Low-Low Antenna
- No Line of Sight
- Lower Frequencies exhibit more Compact Scattering Functions
- Lack of Diffraction Limits Performance on Higher Frequency

Channel Response

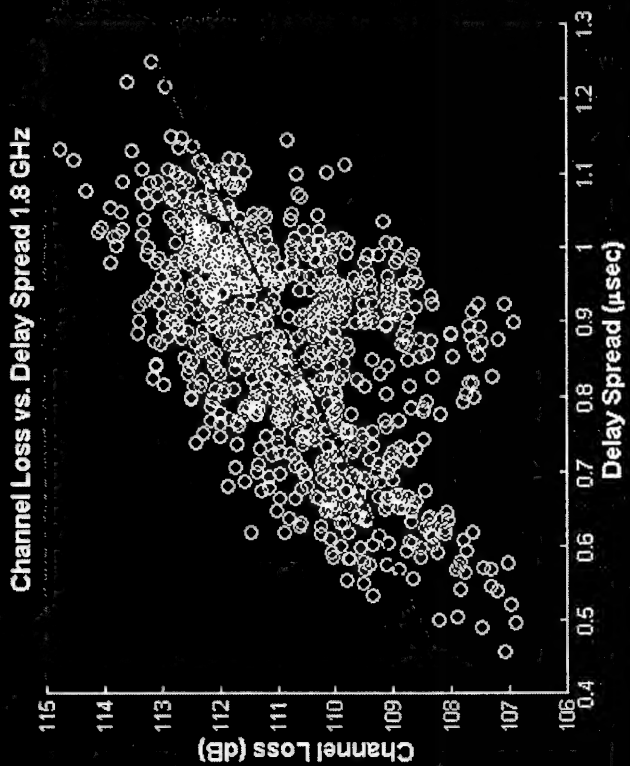
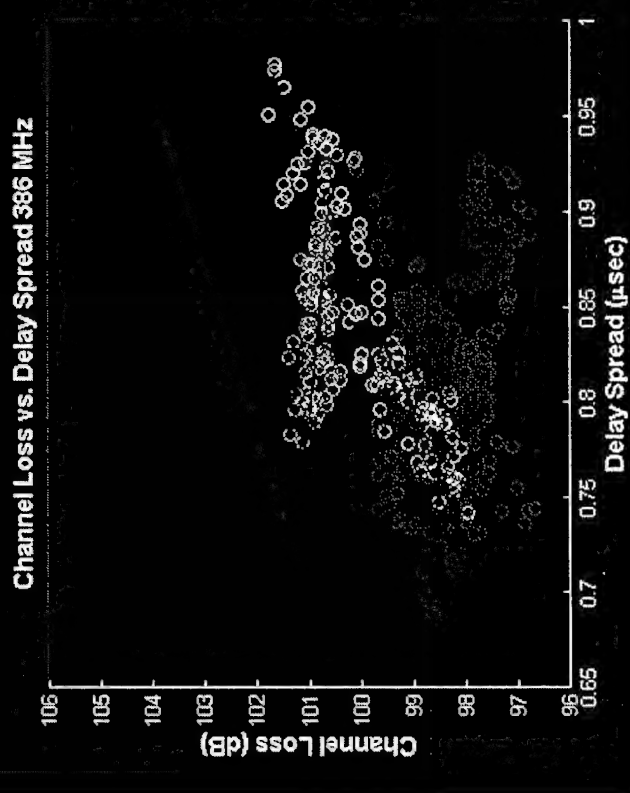
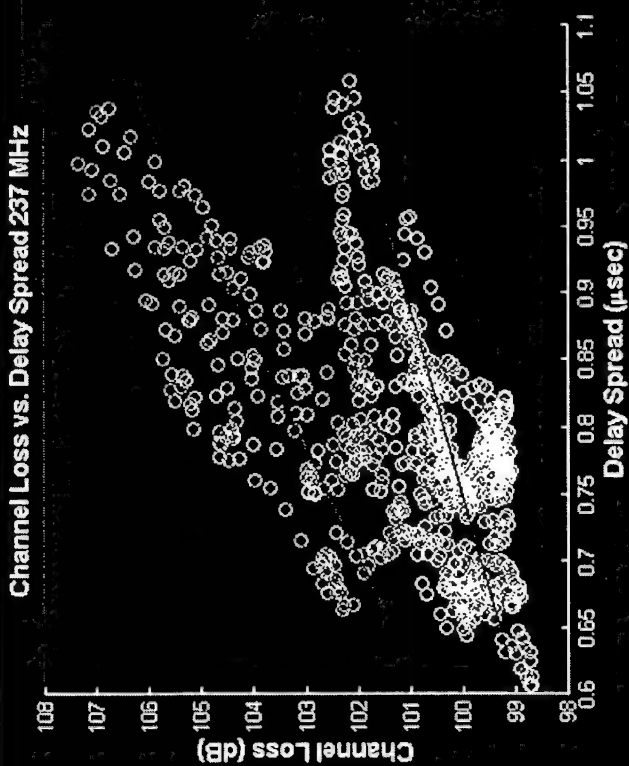
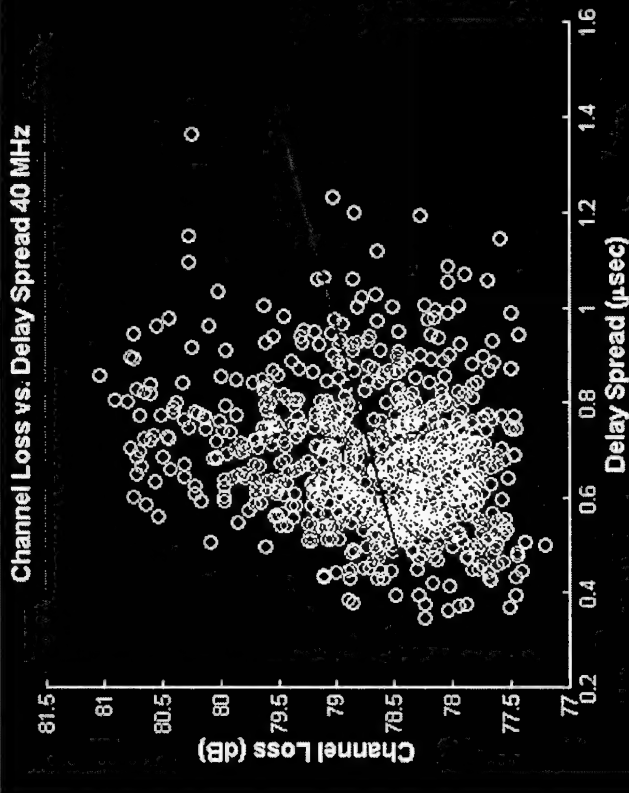


- ~320,000 Channel Estimates taken at 44 kHz
- Averaged to 100 Hz for Power Delay Profiles to Estimate Delay Spread (and Loss)

Channel Loss

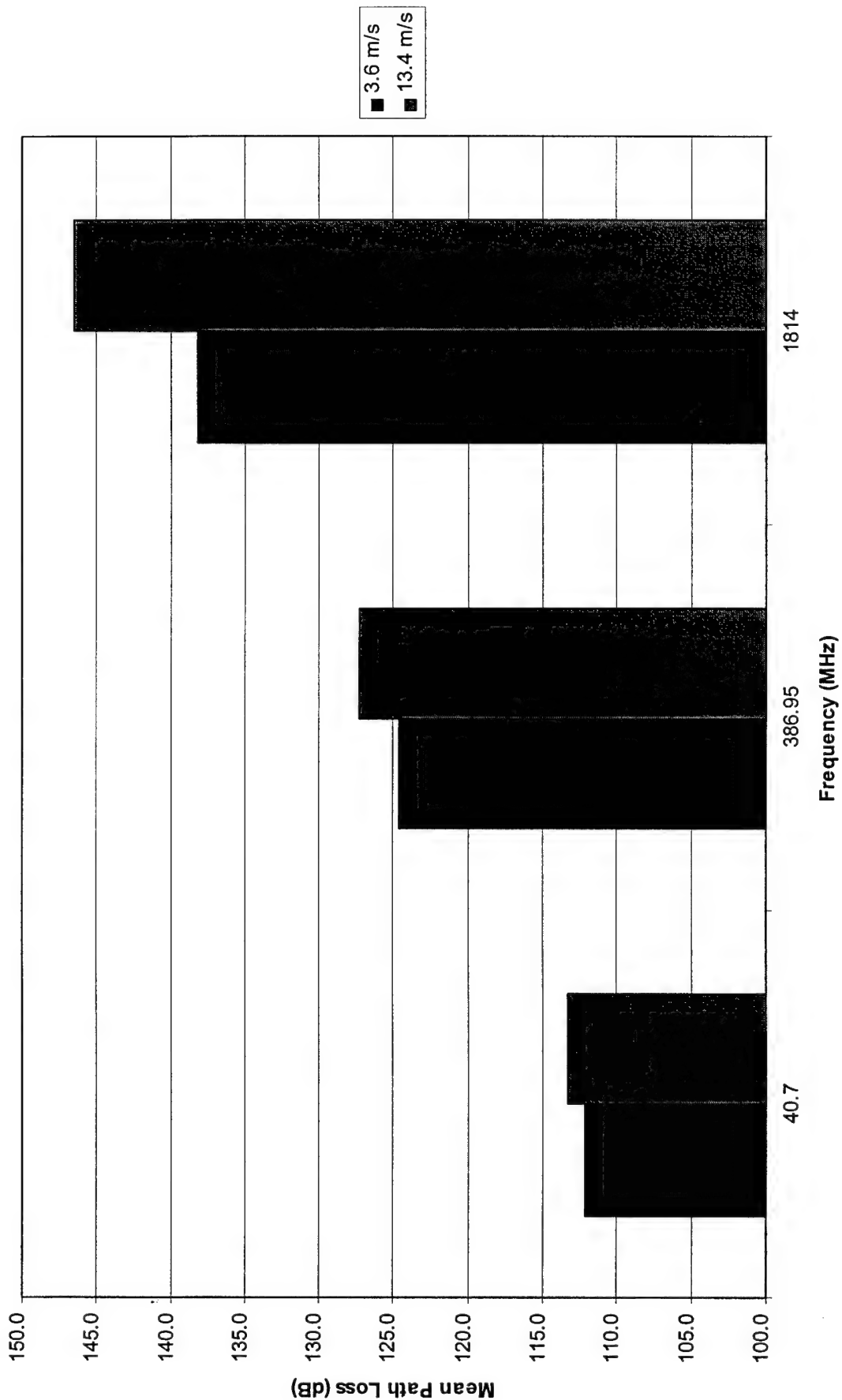


Channel Loss



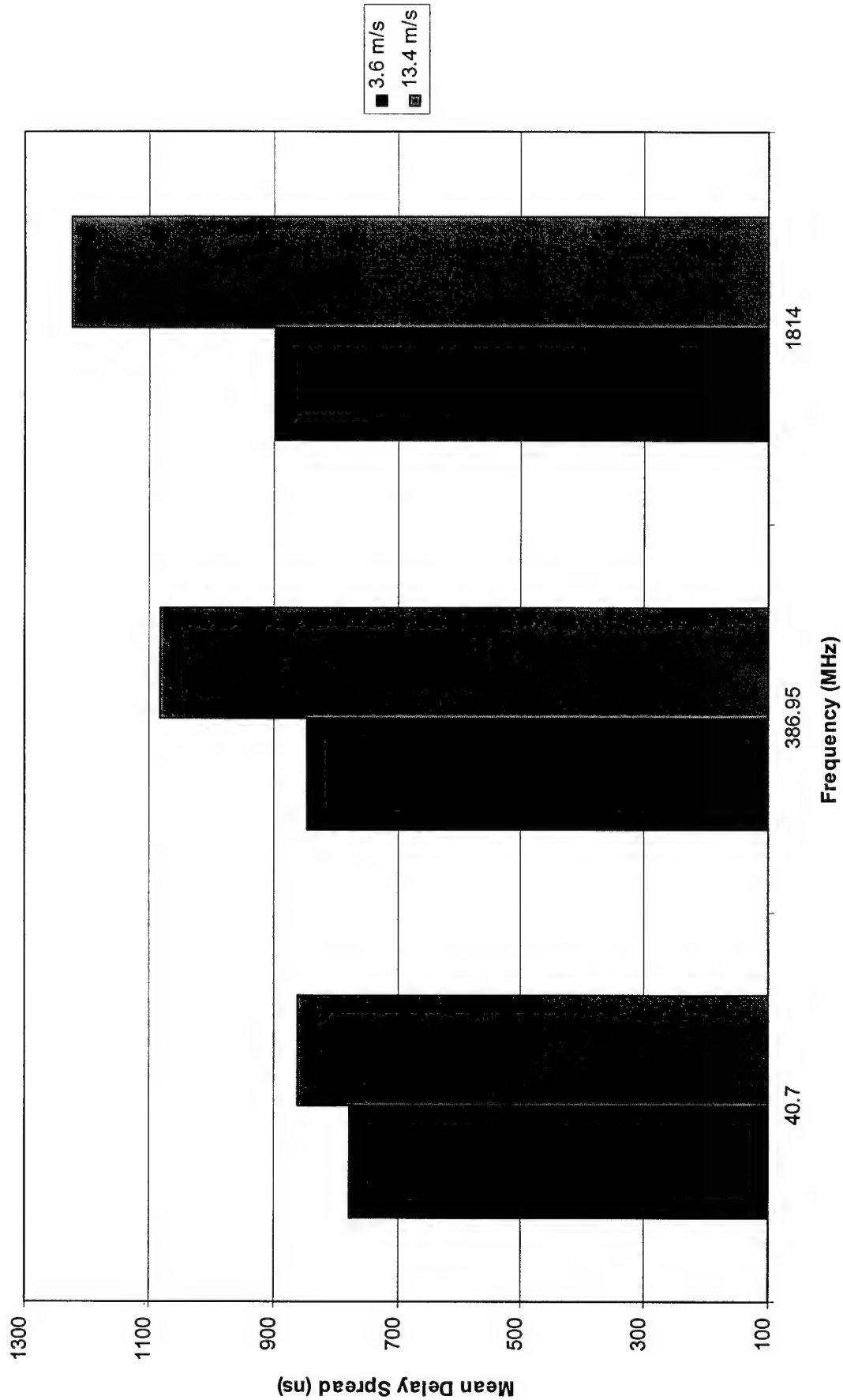
Urban Path Loss

Urban Environment, (Ch. 13; HMMWV Motion)

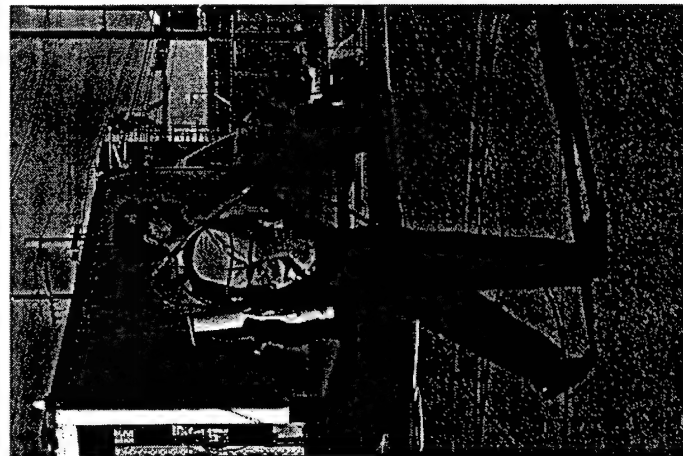


Urban Delay Spread

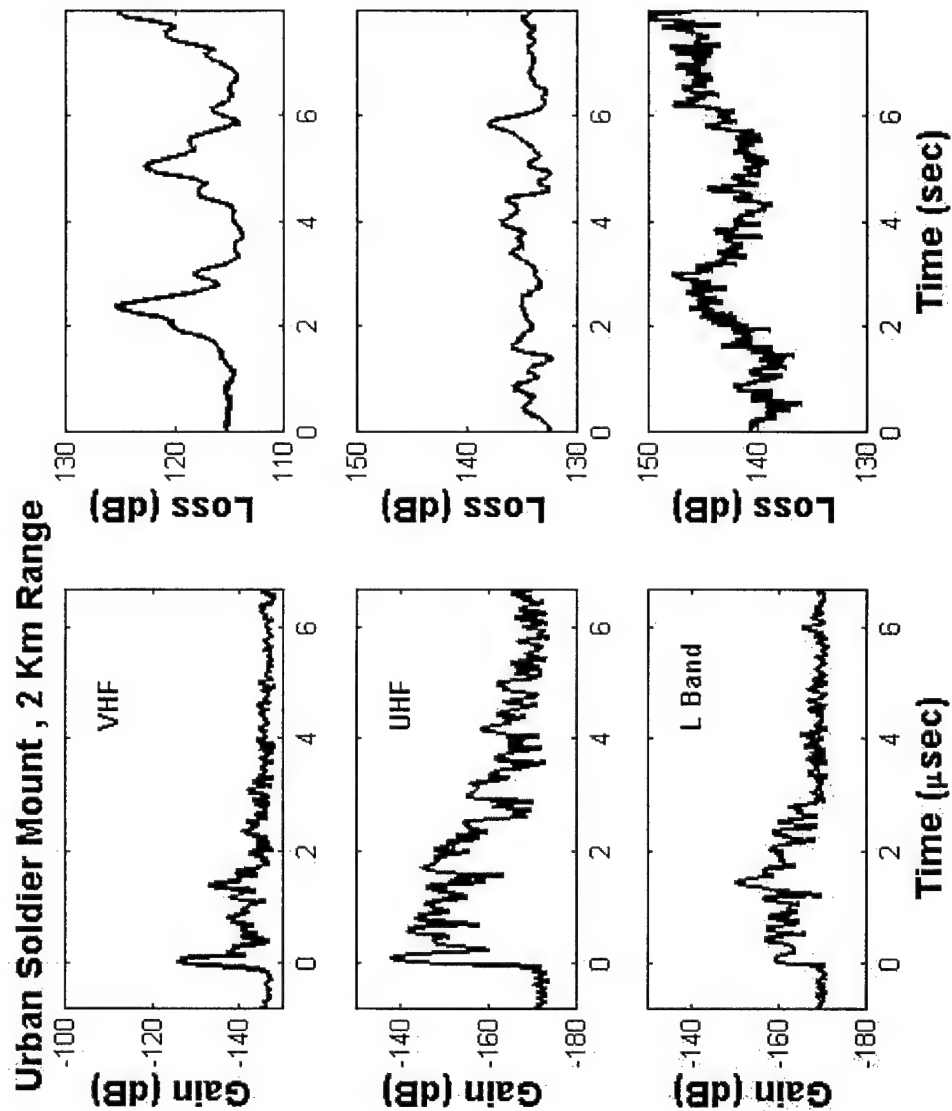
Urban Environment, (Ch. 13; HMMWV Motion)



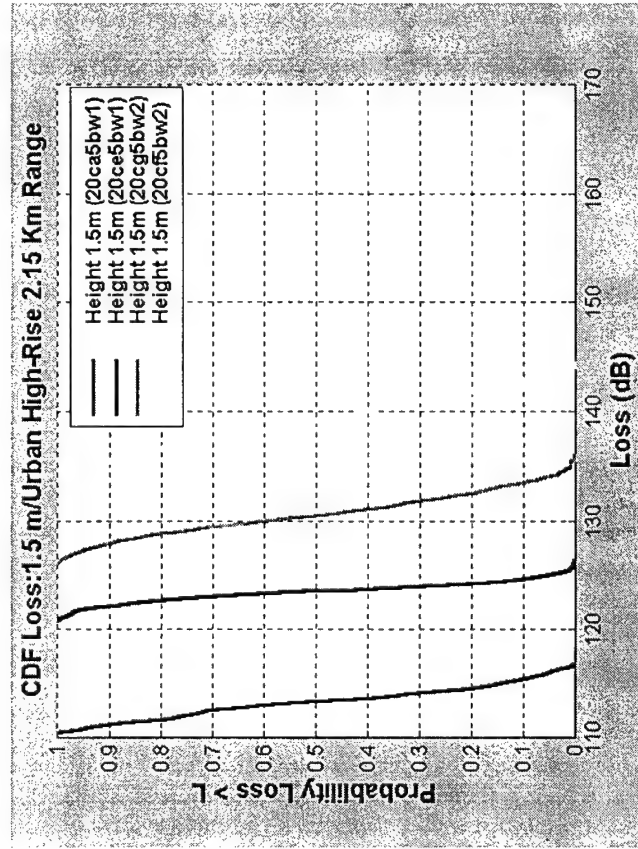
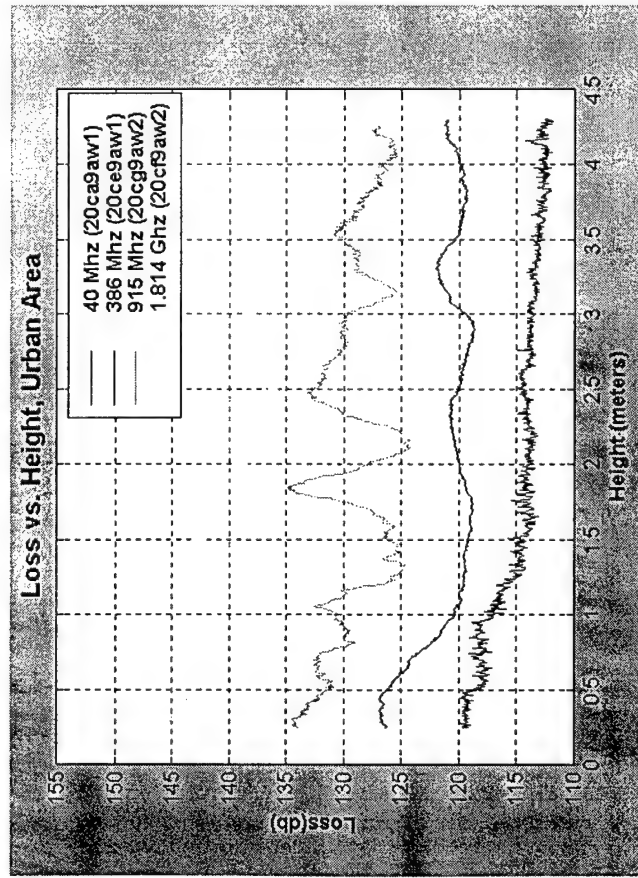
Soldier Mount



Soldier Mount



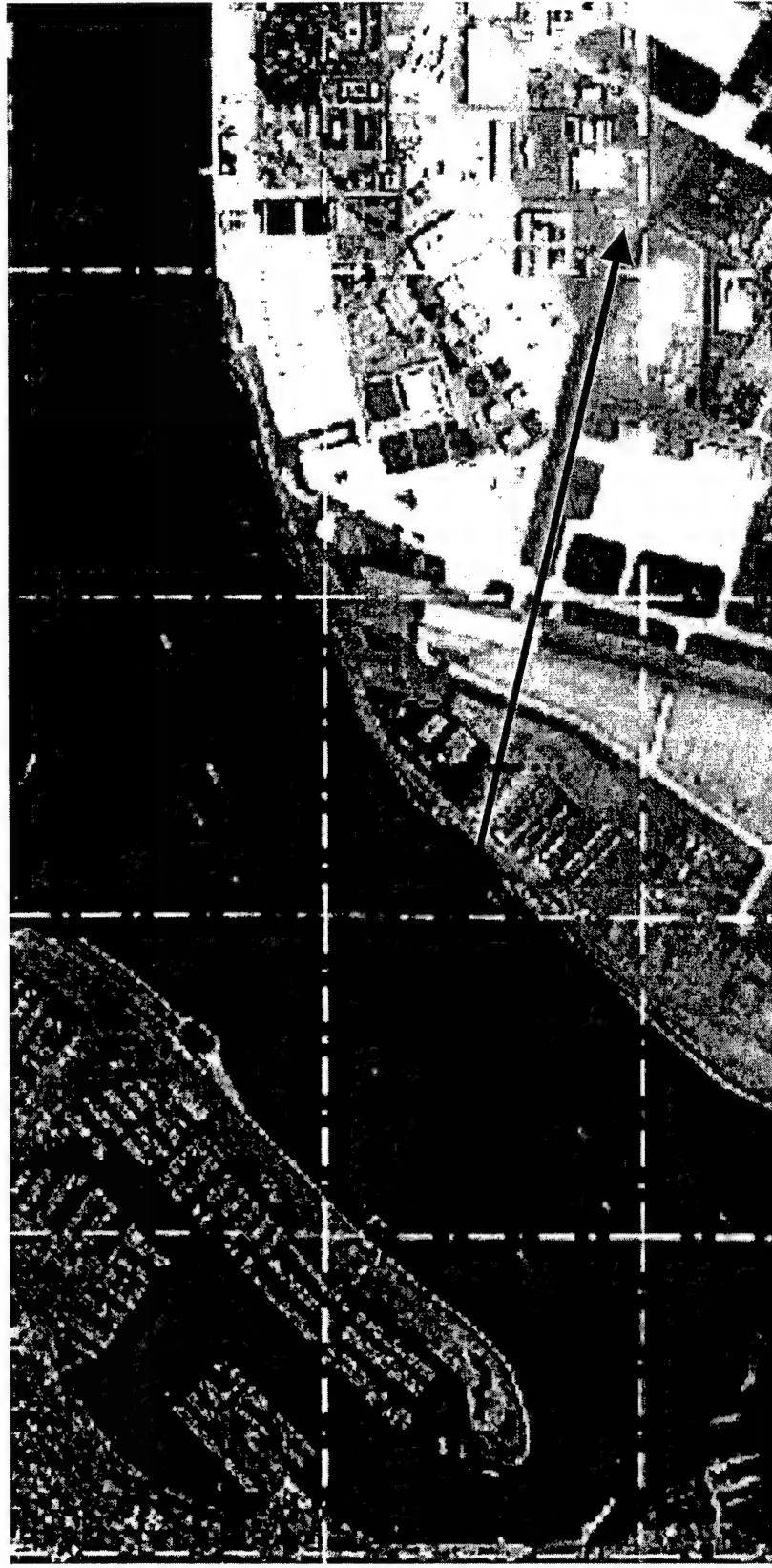
Urban Path Loss vs. Height

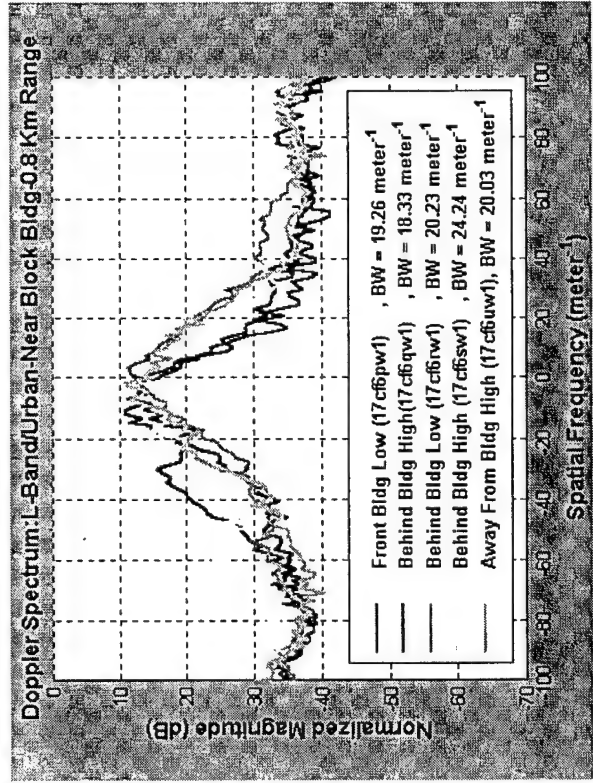
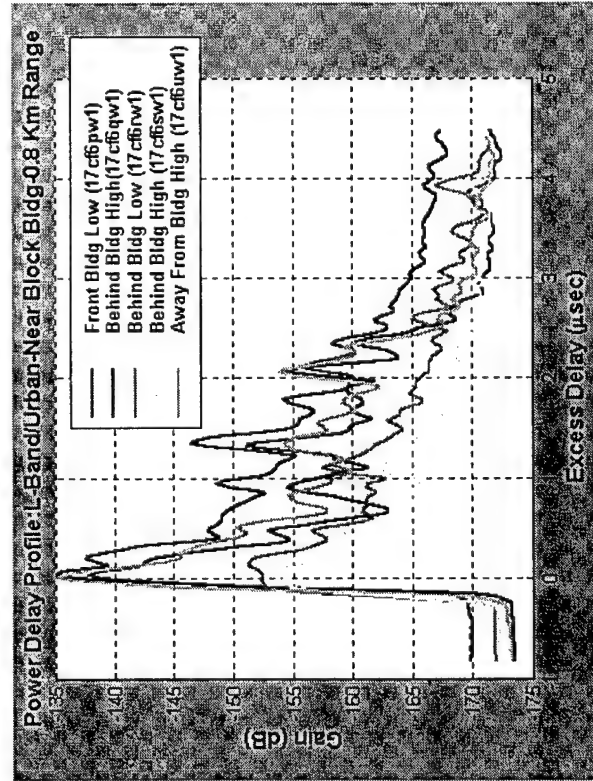
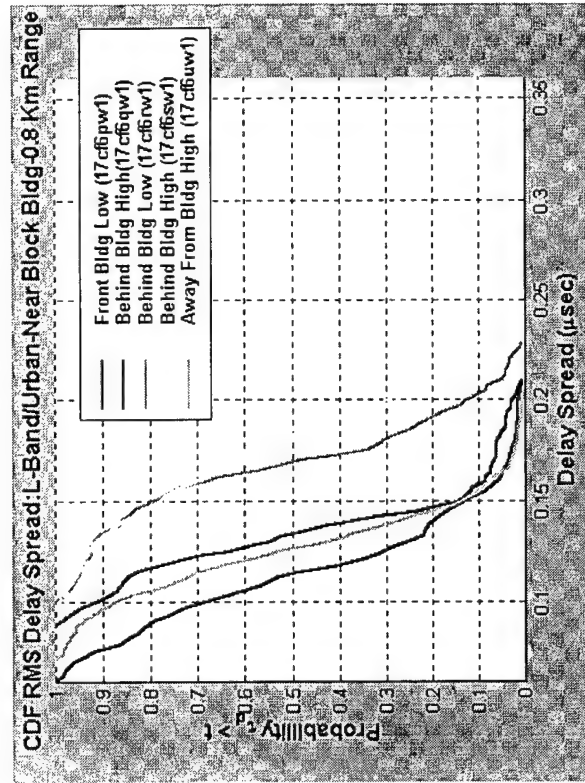
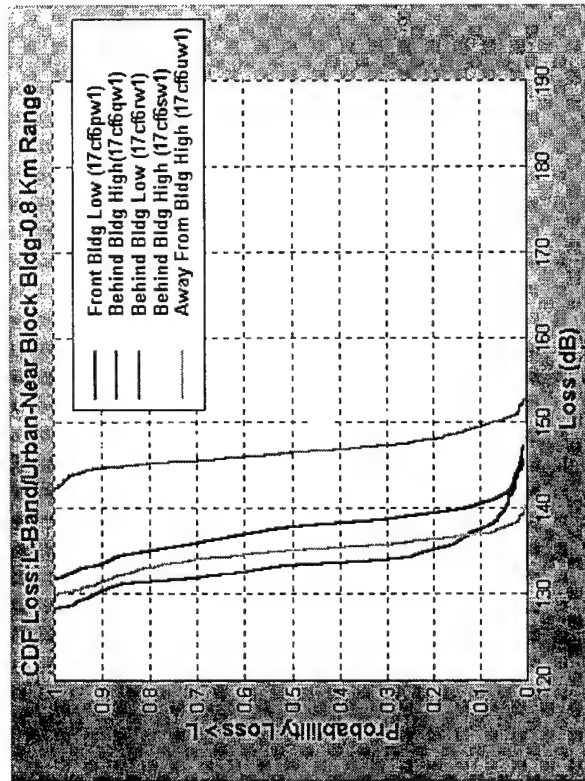


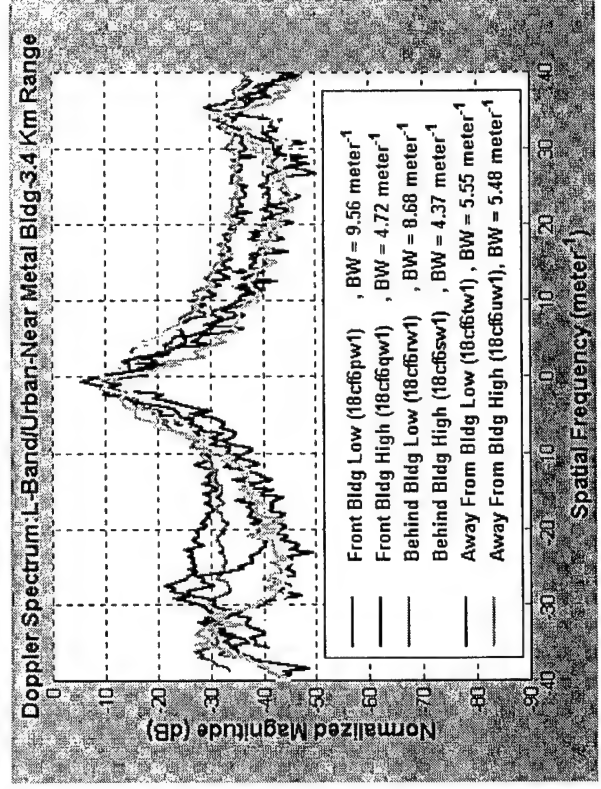
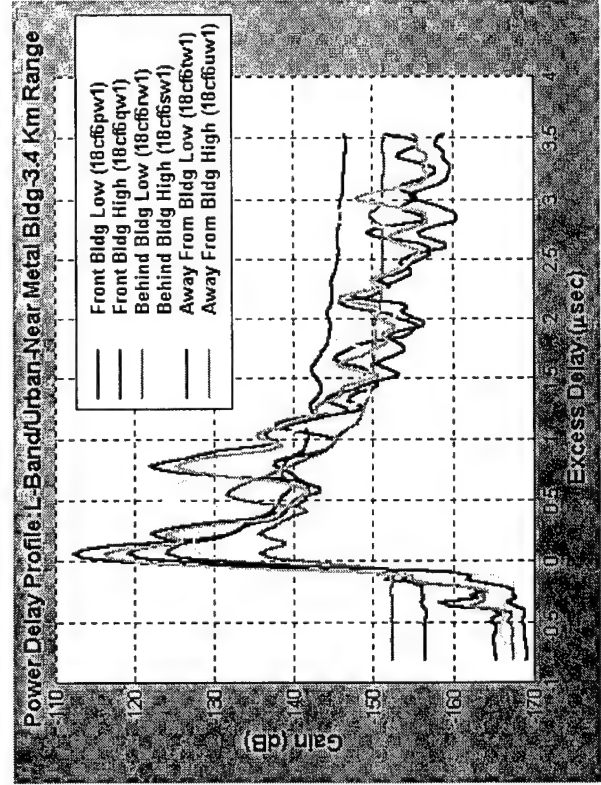
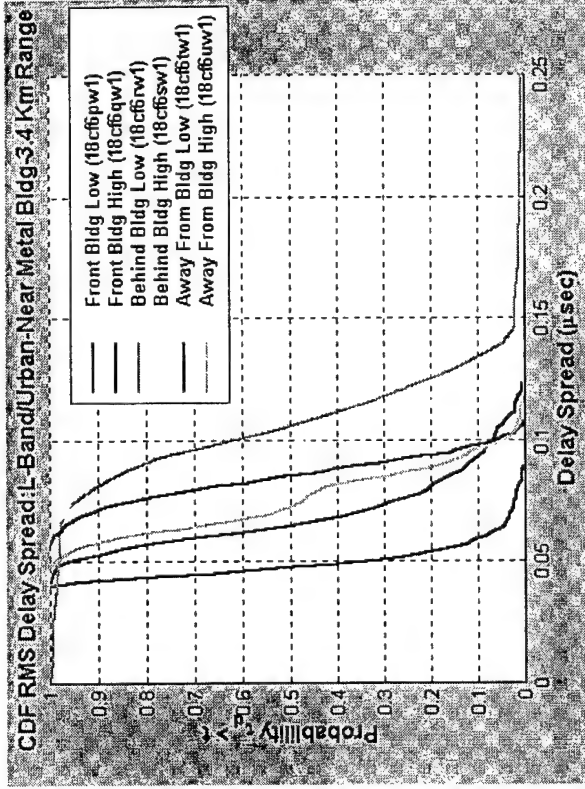
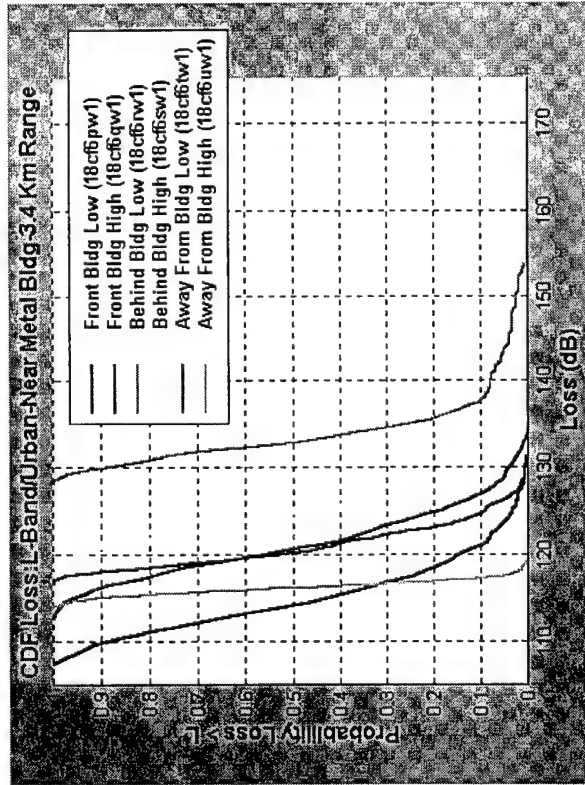
Balboa Park, Block Building

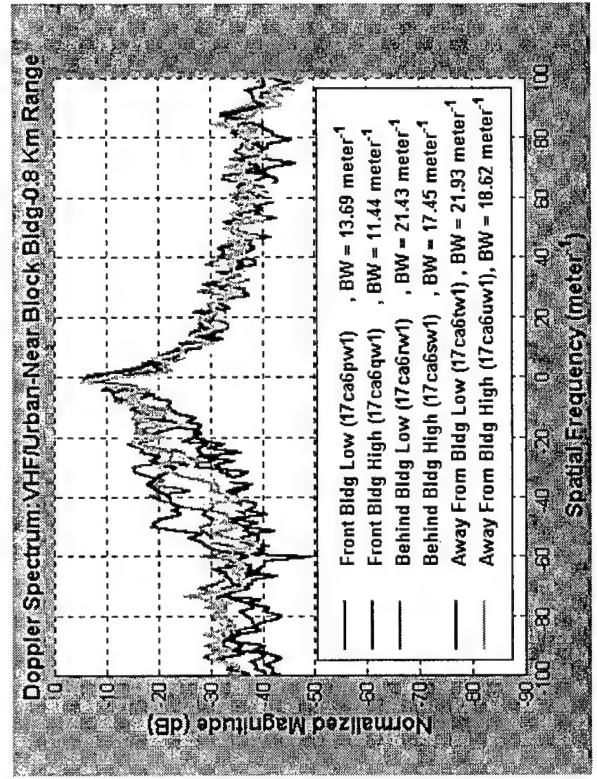
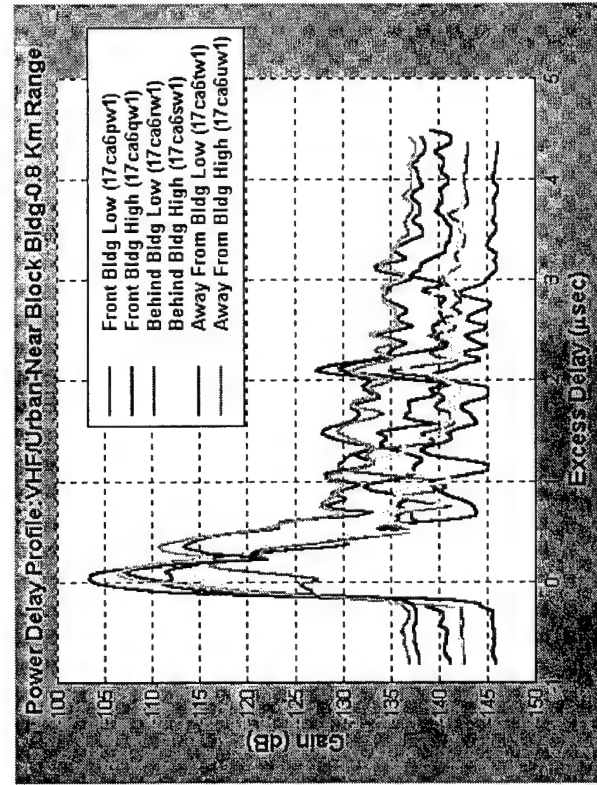
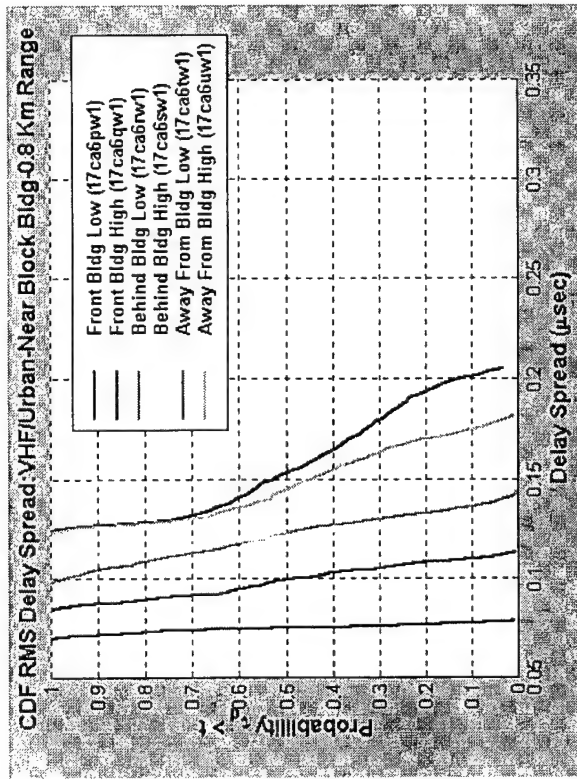
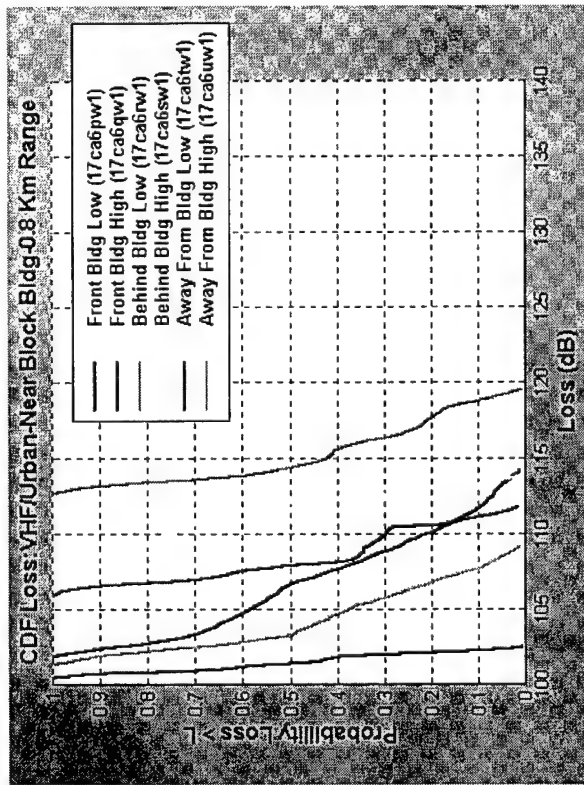


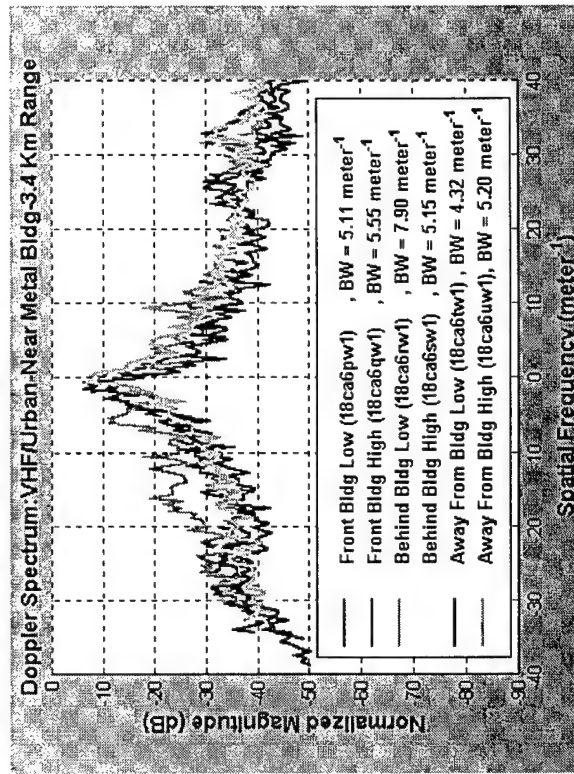
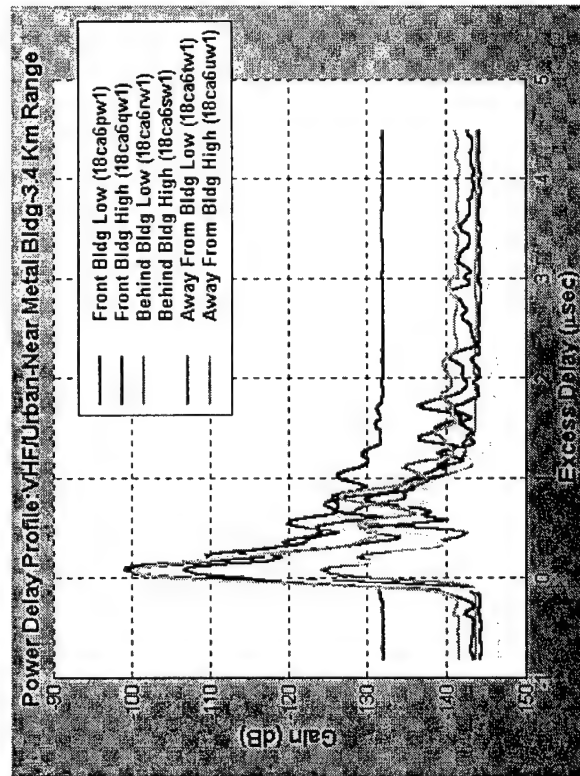
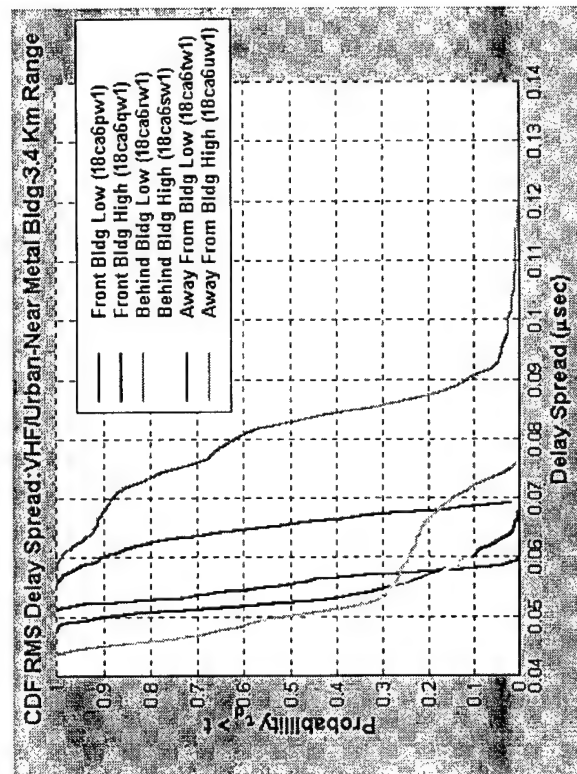
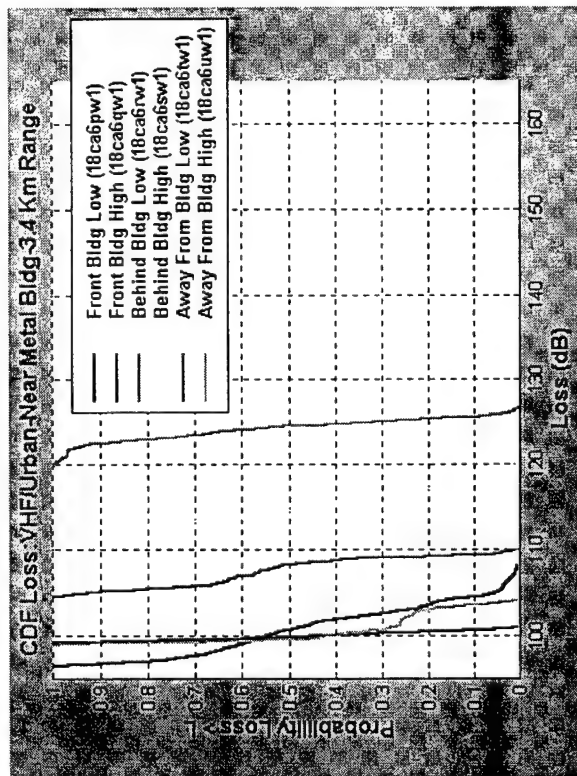
North Island - Metal Building





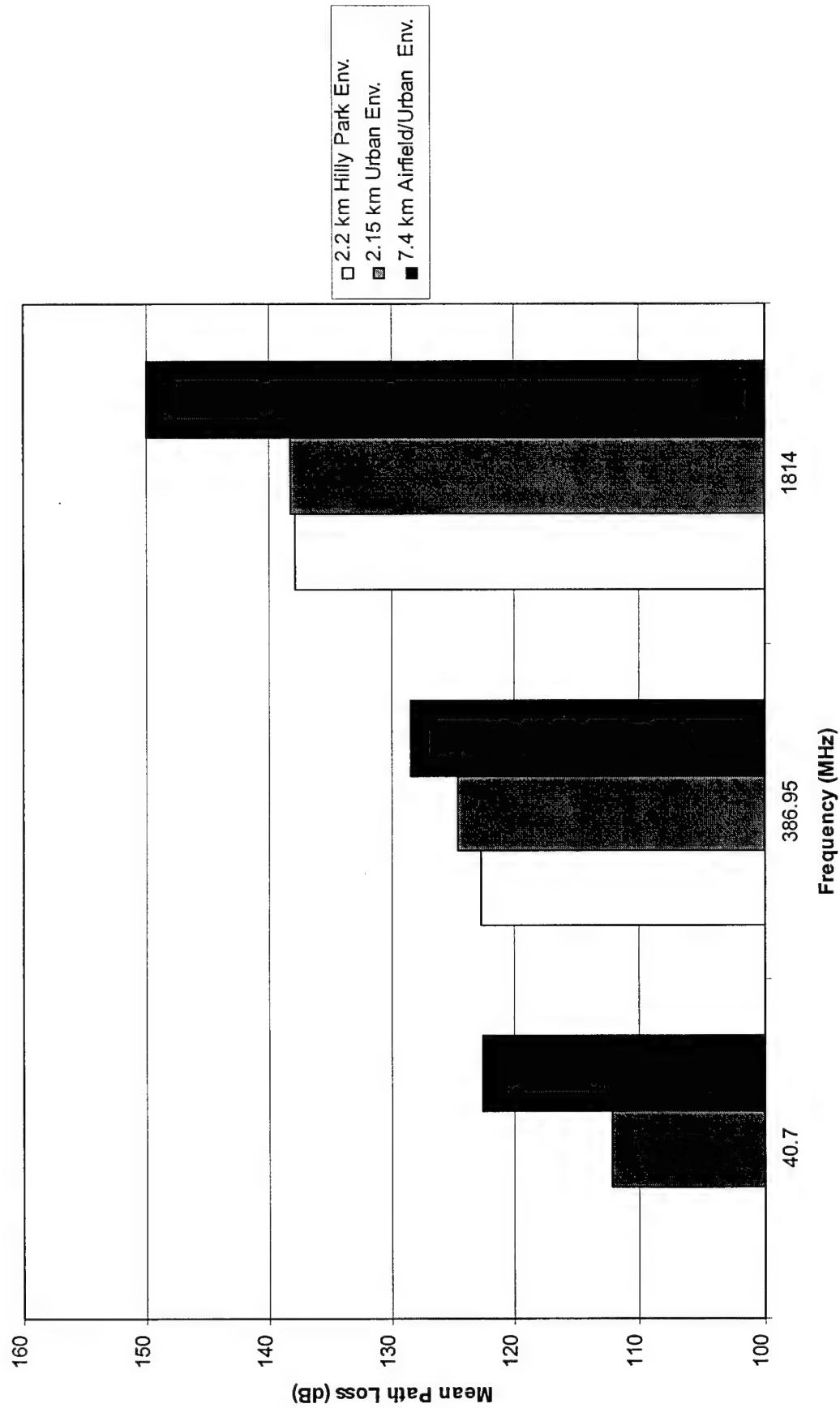






Path Loss vs. Frequency & Environment

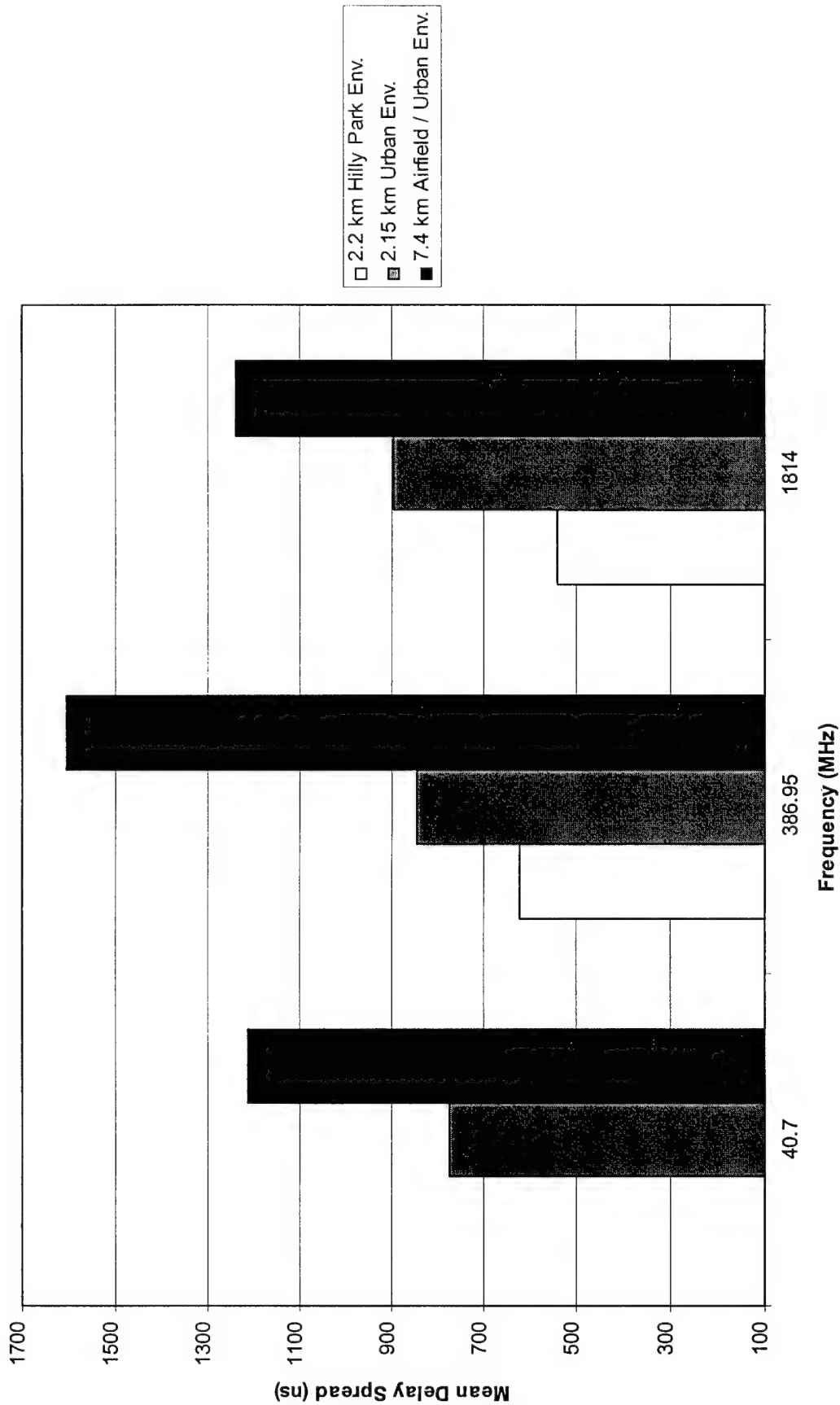
Various Environments (Ch 16, 13, 19; 3.6 m/s HMMWV Motion)



Delay Spread vs. Frequency & Environment

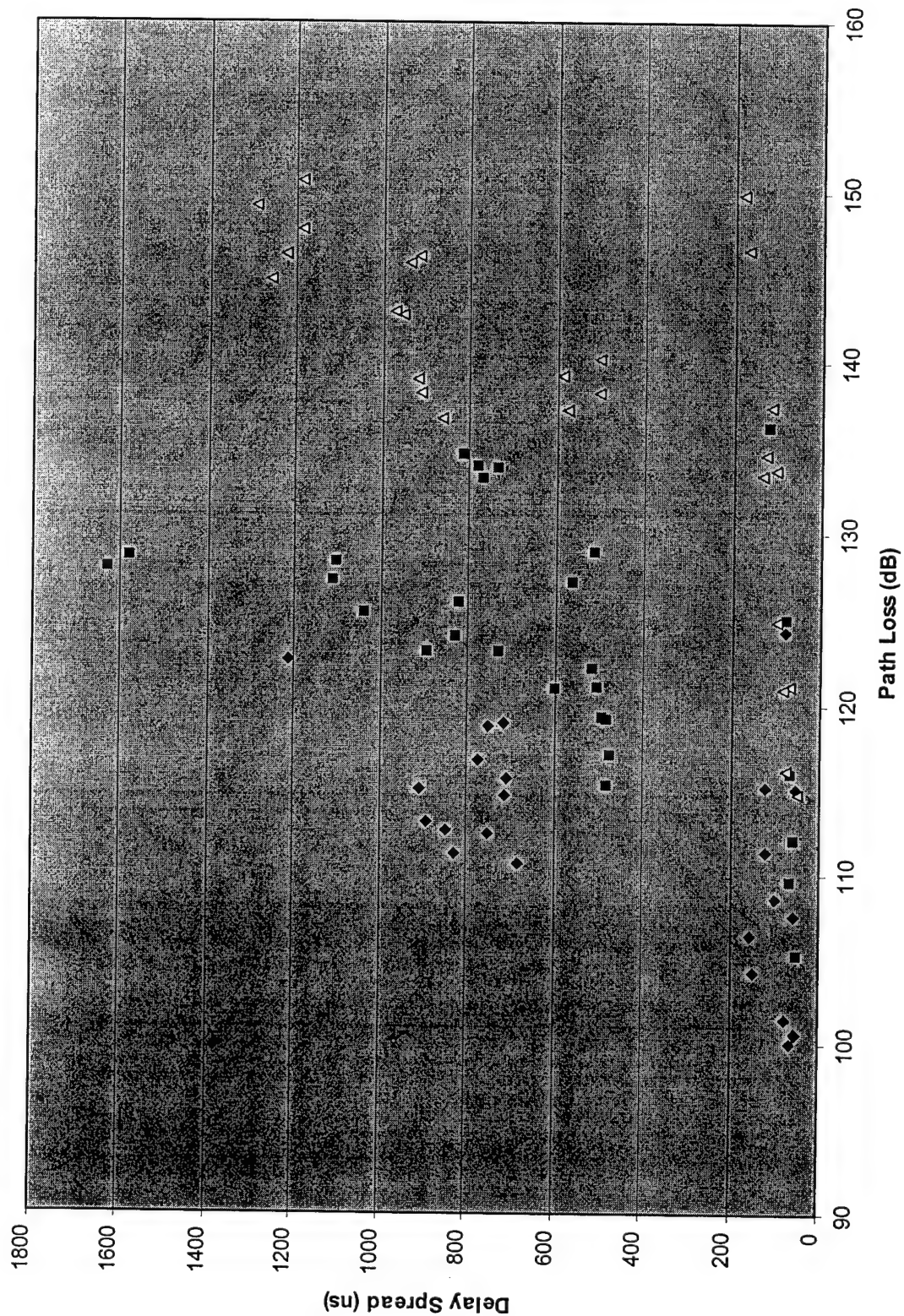


Various Environments (Ch 16, 13, 19; 3.6 m/s HMMWV Motion)



PL-DS Scatter Plot

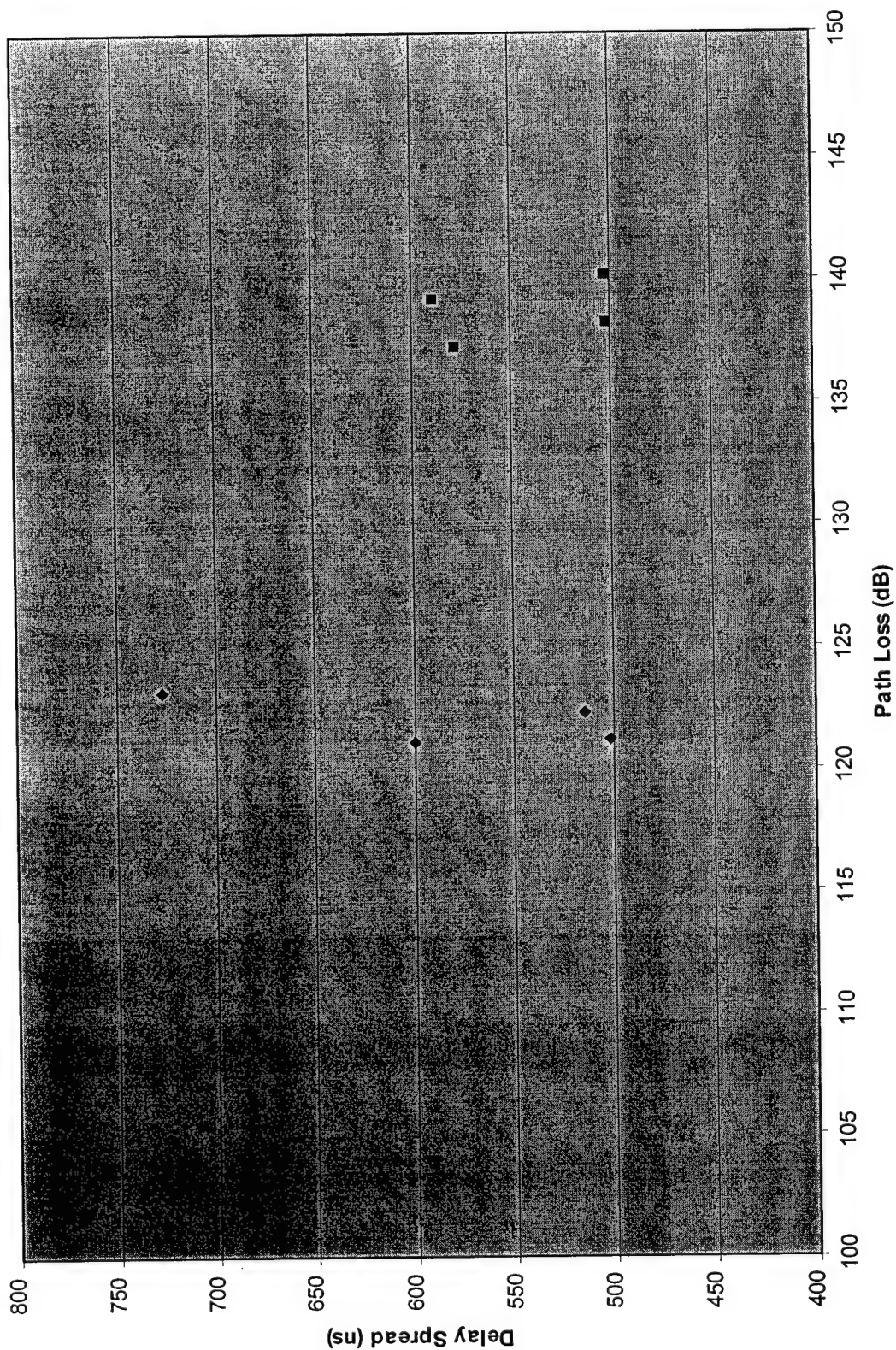
(All Cases Combined)



◆ 40.7 MHz
■ 386.95 MHz
△ 1814 MHz

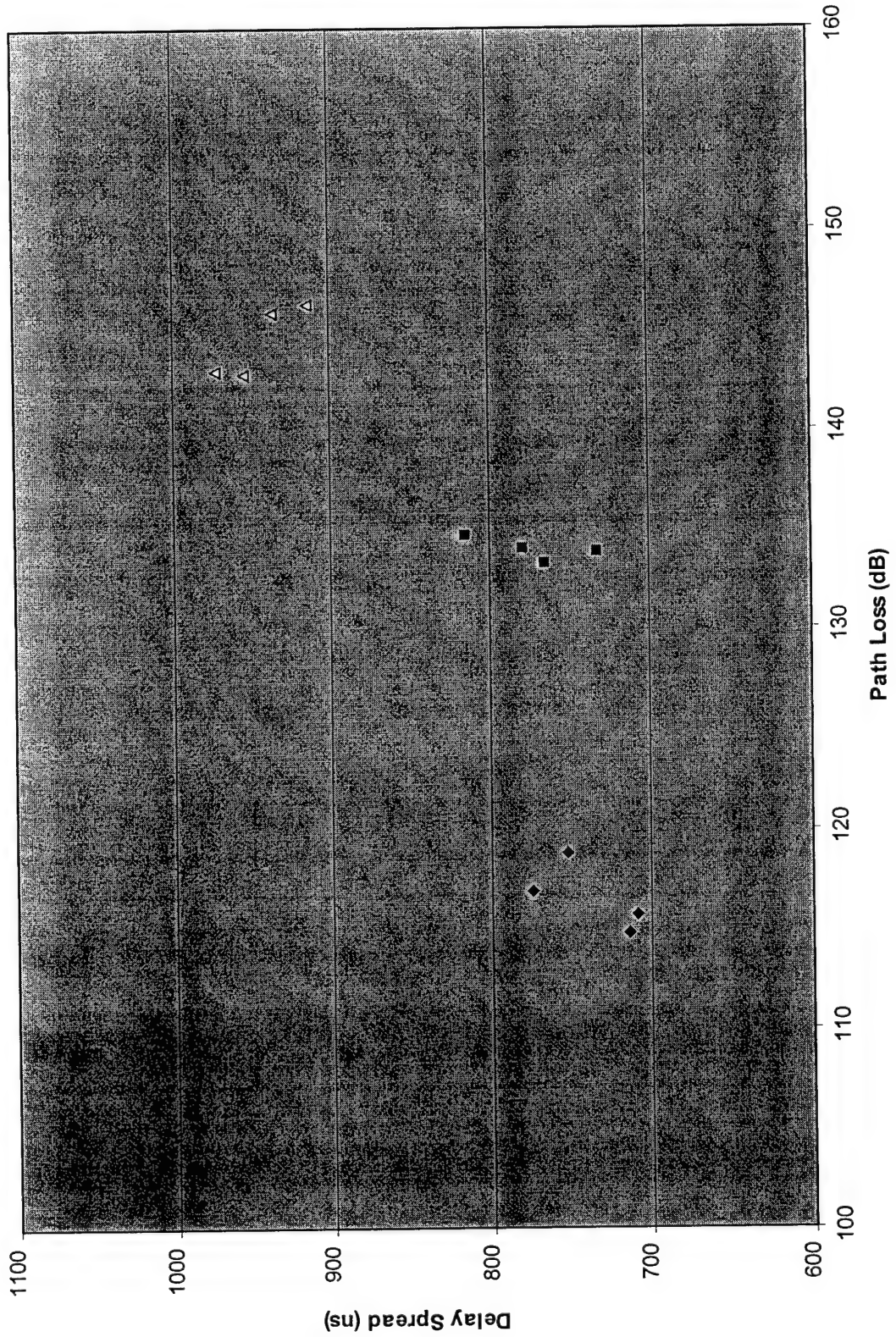
Balboa Park Hills/Trees (2.2 Km)

PL-DS Scatter Plot (Hilly Balboa Park, Ch.16)



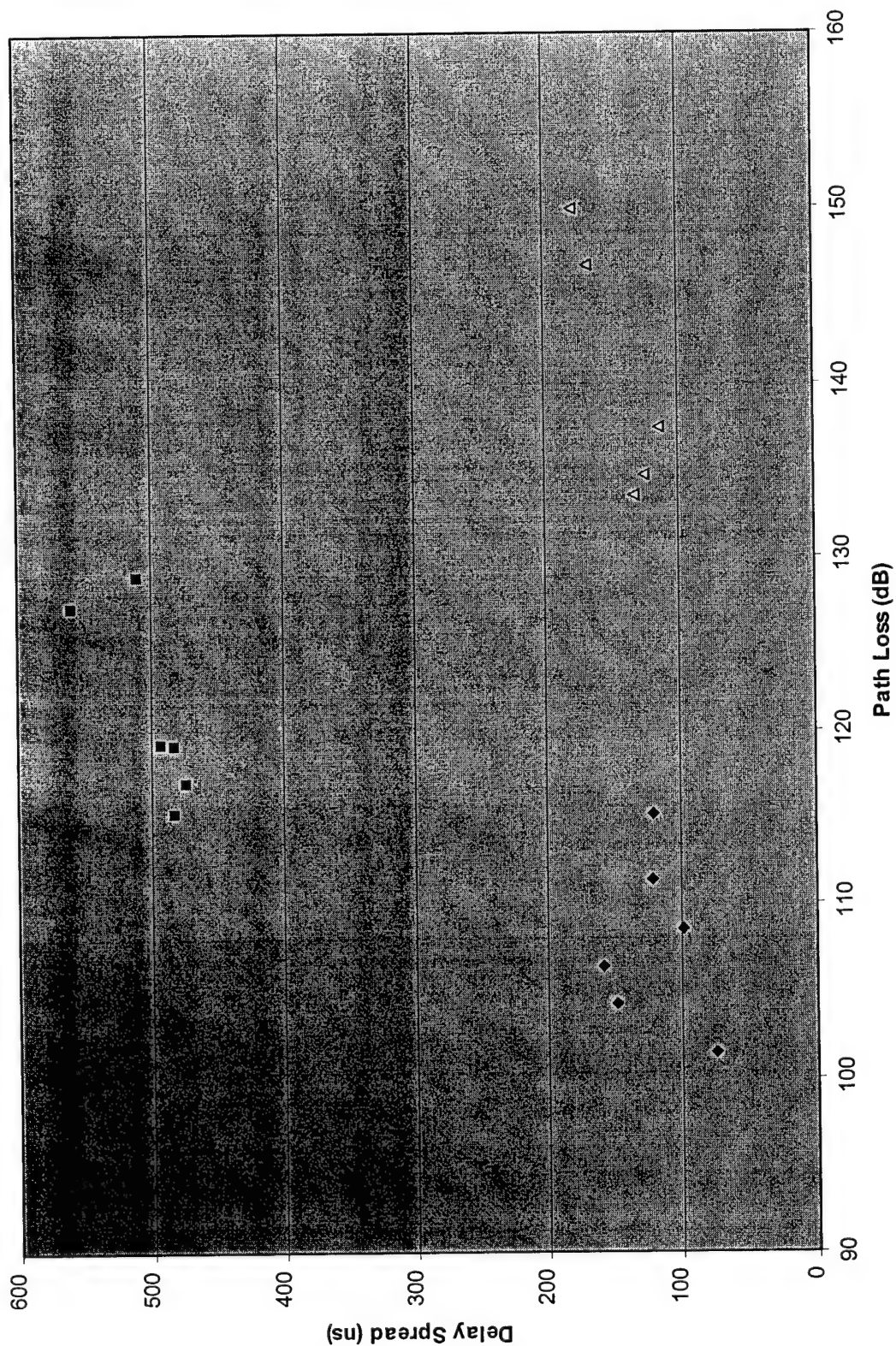
Urban Soldier Mount (2.1 Km)

PL - DS Scatter Plot (Soldier Motion, Ch. 13 & 20)



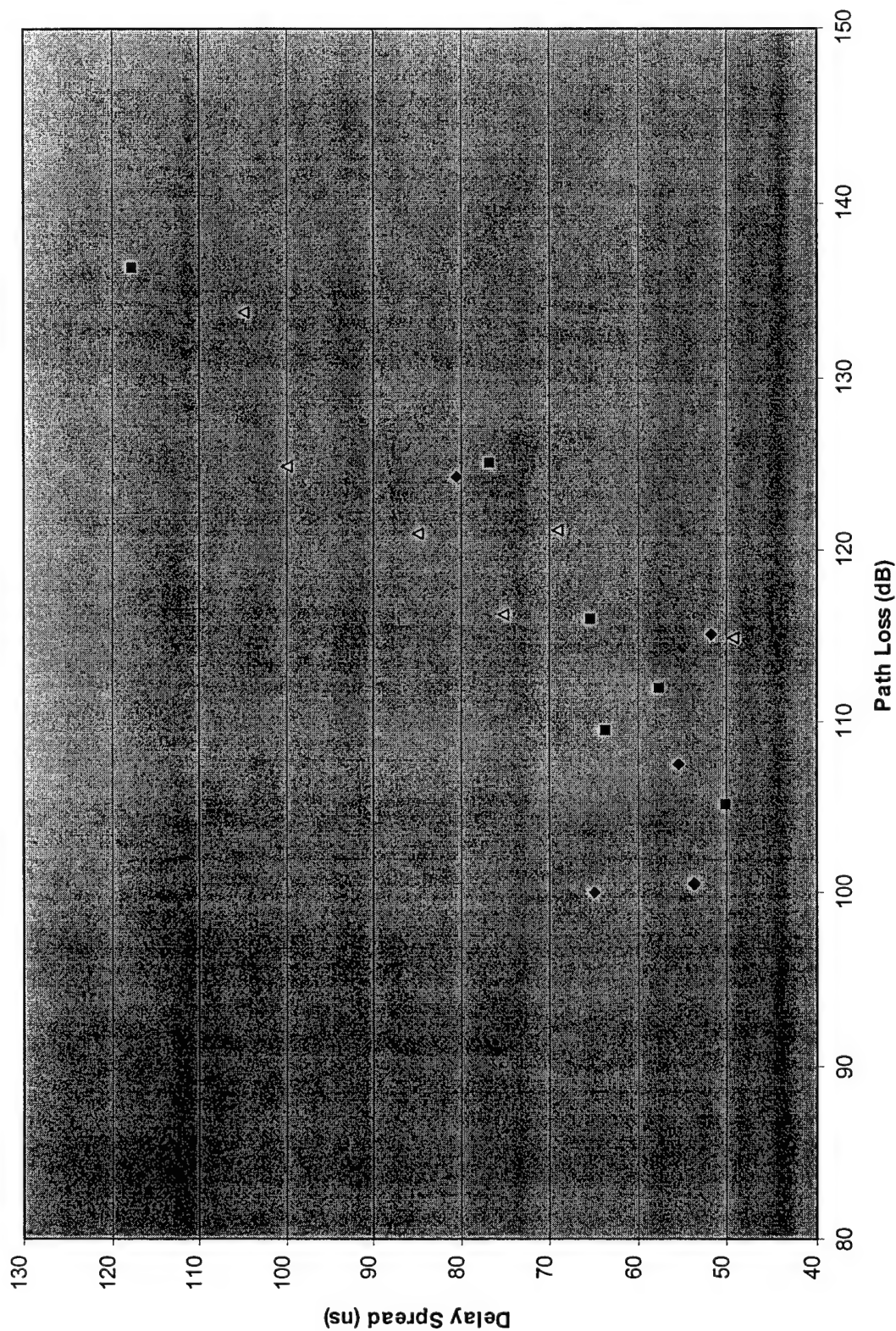
Balboa Park (0.8 Km)

PL - DS Scatter Plot (Block Bldg, Ch. 17)



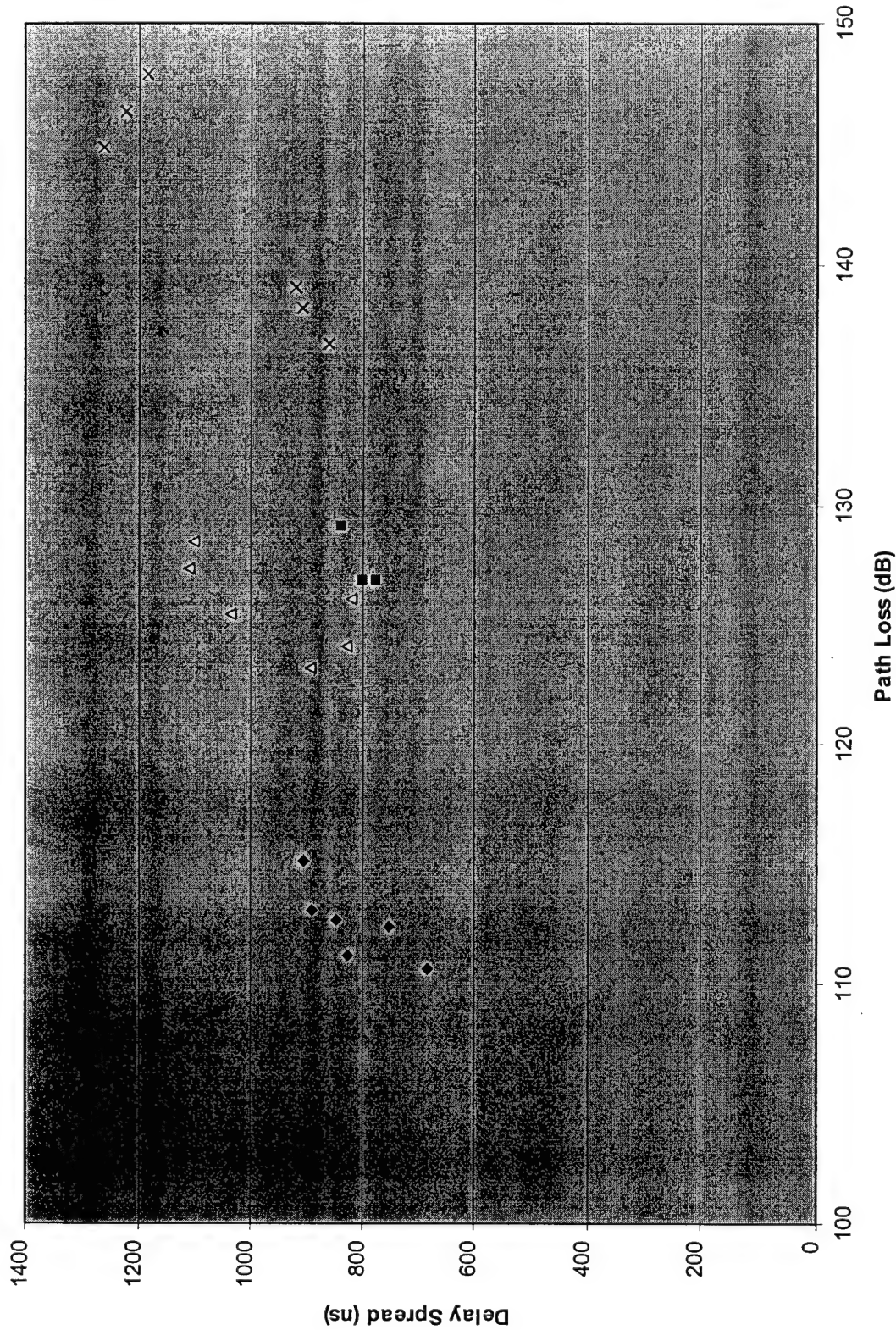
Airfield (3.4 Km)

PL - DS Scatter Plot (Near Metal Bldg, Ch. 18)



Urban HMMWV Mount (2.1 Km)

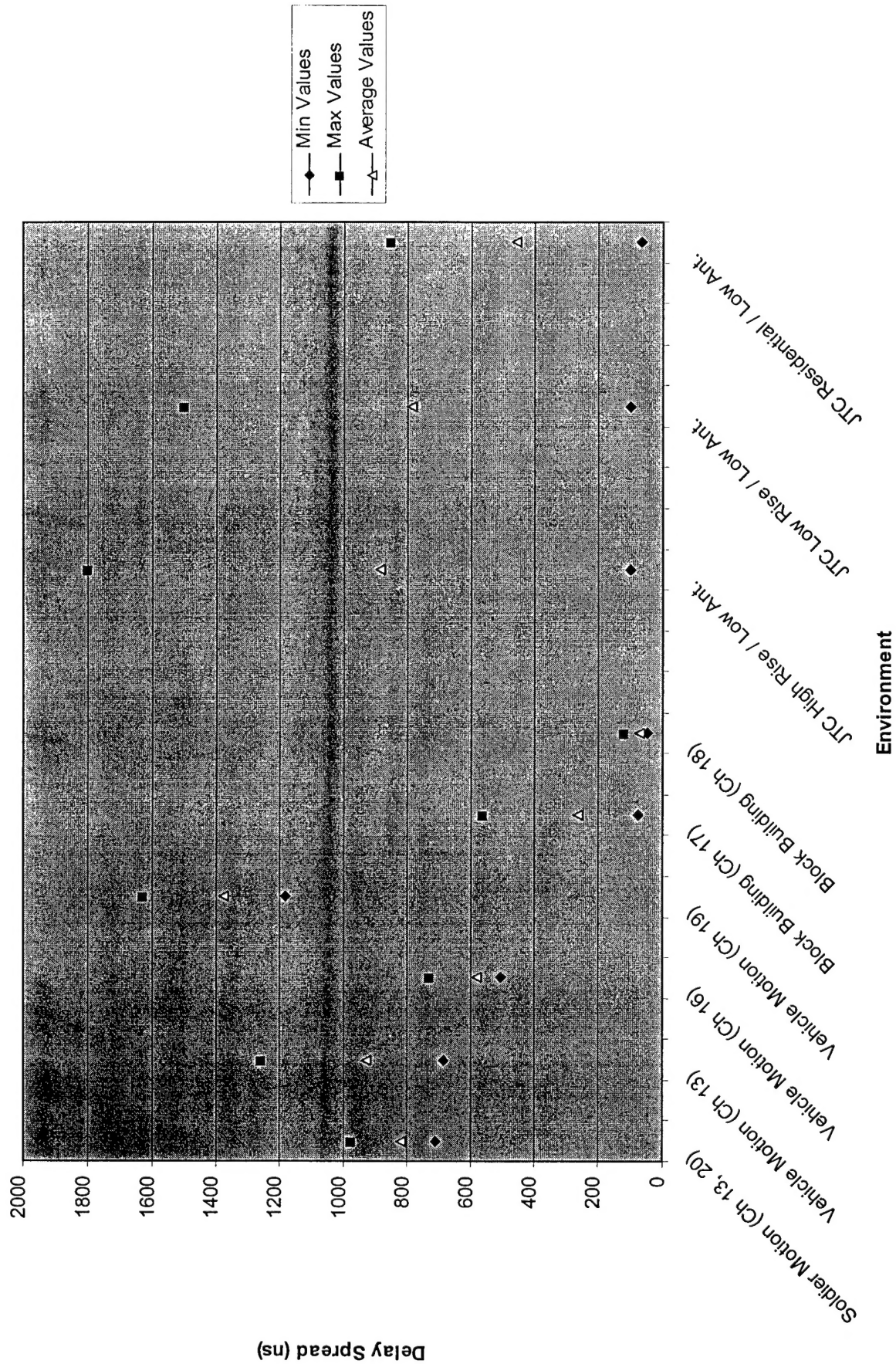
PL - DS Scatter Plot (Urban, Ch. 13)



Outline

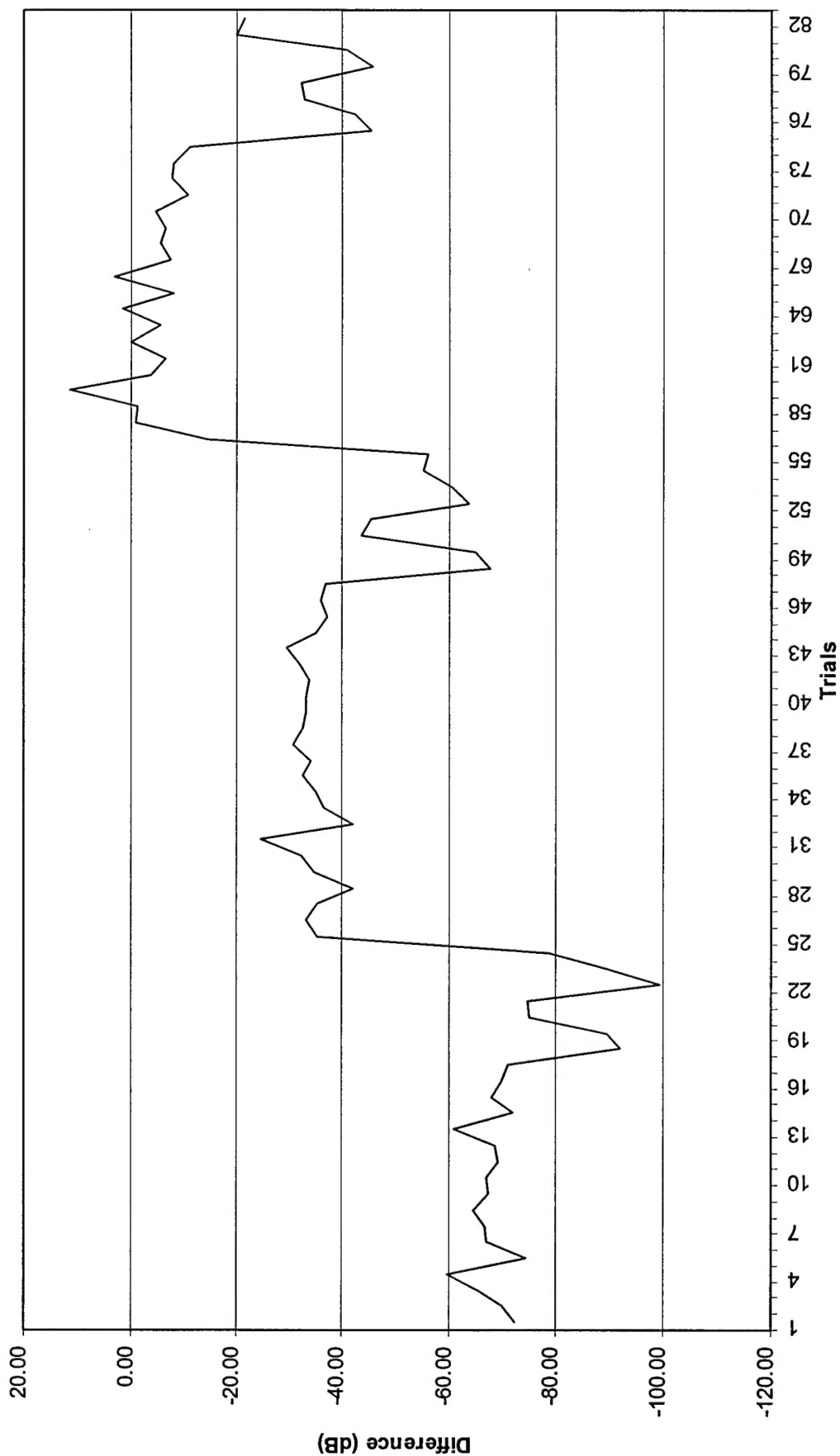
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JTC Model Comparison



JTC Model Comparison

Measured - JTC (dB)
Sorted by Frequency/Distance/Channel



Hata Model Comparison

Measured - HATA (dB)
Sorted by Frequency/Distance/Channel

